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Scientific, Technical and Economic Committee for Fisheries (STECF) - Evaluation of alternative scenarios for Adriatic small pelagic MAP (STECF-OWP-18-02)

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Abstract

Commission Decision of 25 February 2016 setting up a Scientific, Technical and Economic Committee for Fisheries, C(2016) 1084, OJ C 74, 26.2.2016, p. 4–10. The Commission may consult the group on any matter relating to marine and fisheries biology, fishing gear technology, fisheries economics, fisheries governance, ecosystem effects of fisheries, aquaculture or similar disciplines. The Commission requested an Evaluation of alternative scenarios for Adriatic small pelagic MAP. The Scientific, Technical and Economic Committee for Fisheries (STECF) issued its advice by written procedure in January 2018.

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Background provided by the Commission

The European Commission has launched a proposal for an EU MAP on the Adriatic small pelagic stocks[1]. In the MAP ANNEX I and II there are respectively the target fishing mortality F_{MSY} ranges and conservation reference point ($MSY_{Btrigger}$ and B_{lim}, B_{pa}) for sardines and anchovies. These values were derived from STECF-15-14 (2015a) and are now outdated by revised input data and consequent new assessments. Additionally, the framework for proposing a target fishing mortality has change from an F_{MSY} computed in eqSIM, to a Patterson Exploitation rate = 0.4. (see STECF Plenary Report July 2017, PLEN-17-02)

The MAP proposal is currently in discussion with the European Parliament and the Council.

STECF PLEN-17-03 evaluated both the new assessments of Anchovy and Sardine in GSA 17-18 and proposed F and B reference points based on a target F that is a proxy of Patterson E = 0.4. An additional scenario is accounting for a different maturity at age 0 (Mat = 0.5) and corresponding reference points.

The proposed reference points by STECF PLEN-17-03 are the following:

Stock	**Reference point**	**Value**	**Technical basis**
anchovy in GSA 17-18 (MATage0 = 0)	B_{lim}	20155 tonnes	B_0 * 0.2
anchovy in GSA 17-18 (MATage0 = 0)	B_{pa}, $MSY_{Btrigger}$	28007 tonnes	B_{lim}*exp(1.645*0.2)[1]
anchovy in GSA 17-18 (MATage0 = 0)	FMSY	0.57	E=0.4
anchovy in GSA 17-18 (MATage0 = 0.5)	B_{pa}	44712 tonnes	B_0 * 0.2
anchovy in GSA 17-18 (MATage0 = 0.5)	B_{lim}	32 177 tonnes	Blim*exp(1.645*0.2)
sardine in GSA 17-18	B_{lim}	112922 tonnes	B_0 * 0.2
sardine in GSA 17-18	B_{pa} , $MSY_{Btrigger}$	156913 tonnes	B_{lim}*exp(1.645*0.2)[1]
sardine in GSA 17-18	FMSY	0.44	E=0.4

As the above mentioned stock assessments and STECF advice have significantly changed the advice on which the MAP proposal has been built, an additional management strategy evaluation work to evaluate alternative scenarios for managing these stocks in the short to medium term is needed to be carried out through an ad-hoc contract and with technical support from JRC.

The contract should support the STECF to build medium term forecast scenarios according to the proposed reference points and to different timings for achieving the F_{MSY} proxy with associated risk.

[1] Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL establishing a multi-annual plan for small pelagic stocks in the Adriatic Sea and the fisheries exploiting those stocks {SWD(2017) 63 final} {SWD(2017) 64 final}

Request to the STECF

For the stocks of anchovy (according to age0 MAT = 0 or 0.5) and sardine in the Adriatic Sea, evaluate in an MSE framework the sustainability of the management scenarios described below, considering the HCR parametrized by PLE1703, and taking into account recruitment variability from TOR 1 and sensitivity to natural mortality assumptions. As much as possible follow the methodologies used in other MAPs evaluated by STECF.

Management scenarios:

Time limit: 2030

The different scenarios should be compared with a scenario of fishing at F status quo (average F at age of the last three years)".

Tactics:

- linear reduction in F up to years 2020 or 2025 starting in:
    - 2019
    - 2020
- catch reduction of 10% or 20% per year
    - starting in:
        - 2019
        - 2020
    - HRV scenario
        - in 2018 the catch limit for small pelagics shall be set at the level of catch in 2014. Starting from 2019, catch limits for small pelagics shall be gradually reduced each year by 5 % in comparison to the previous year until 2022

Summary of the information provided to STECF

The STECF response is based on the results presented in the ad-hoc contract report (Annexes I-III). A number of Management Strategy Evaluations (MSE) were run for both anchovy and sardine, comparing the results of the different management scenarios described above via simulation testing, taking into account alternative assumptions about stock dynamics.

Four different assumptions about maturity and natural mortality were tested for anchovy, and two were tested for sardine. These six simulated population dynamics, referred to as Operating Models (OM) are conditioned on the most recent stock assessment data.

OM	Stock
OM1	Anchovy (maturity at age0 set to 0, as in STECF PLEN 17-03)
OM2	Anchovy (mat0=0 and constant M)
OM3	Anchovy (maturity at age0 set to 0.5 as in GFCM Small

	pelagics 2017
OM4	Anchovy (maturity at age0 set to 0.5; constant M)
OM5	Sardine
OM6	Sardine (constant M)

For each OM, ten management scenarios were tested:

Scenario	Tactic	Period
SQ	Status quo: F constant at 2016 level	All years
S1	Linear reduction of F towards FMSY	2019-2025
S2	Linear reduction of F towards FMSY	2020-2025
S3	Linear reduction of F towards FMSY	2019-2020
S4	10% Catch reduction per year	Start 2019
S5	10% Catch reduction per year	Start 2020
S6	20% Catch reduction per year	Start 2019
S7	20% Catch reduction per year	Start 2020
S8	catch in 2018 equal to 2014 catch for the stock; 5% reduction per year	2018-2022
S9	catch in 2018 equal to total 2014 catches combined anchovy + sardine (115776 t); 5% reduction per year	2018-2022

S8 and S9 are two different interpretations of the HRV scenario, with S8 assuming the same levels of catch and proportion between anchovy and sardine as in 2014 (33157 t + sardine 82619 t respectively) while S9 assumes an extreme and unlikely scenario of fleets targeting one species alone and all catches being directed on that single stock.

In total, 60 runs are thus presented in the report. All runs assume a Hockey-stick stock-recruitment relationship conditioned on the whole time series, similarly to what has been used in STECF PLEN 17-03 to derive reference points.

STECF comments

STECF notes that the simulations outcomes are more optimistic when using the assumption of juvenile anchovy maturity at age 0 = 0.5 than when assuming maturity at age 0 = 0. Therefore, only the results using mat age 0=0 are commented here, since they represent the higher risk boundary. Robust management scenarios providing low risk at mat age 0=0 will de facto present even lower risks under alternative maturity assumption.

STECF recalls that changes in maturity scales have been suggested during the GFCM Small pelagic WG in November 2017 shortly after completion of STECF EWG 17-09 and PLEN 17-03. As such (and as explained in STECF PLEN 17-03 report), B_{lim} with the new maturity scale has not been recalculated using a full modelling exercise with EqSim as performed in PLEN 17-03, but only as a rapid upscaling of B0 (virgin biomass) assuming different maturity parameters for juveniles. At virgin biomass, the proportion of adults in the population is large, which induced an upscaling of B_{lim} by a factor of 1.6 (from 20155 t to 32177t). However, the anchovy populations simulated over the short-medium term have low proportions of adults, and the upscaling of SSB because of the assumed maturity for juveniles has a comparatively larger effect, with a scaling factor of 2 to 3. Therefore, the risks of falling below B_{lim} are much lower with the new maturity scale (OM3) than with the one used by PLEN 17-03 (OM1). The current value of B_{lim} estimated assuming the proportion mature at age 0 = 0.5 is questionable and STECF considers that it should be re-estimated properly using the same methodology as in PLEN 17-03.

STECF notes also that all the catch-based scenarios (S4 to S9) assumes that management would still impose catches reduction even after F_{MSY} has been reached, which may seem unlikely to happen. Alternative scenarios where F would be maintained at F_{MSY} after the initial catch reductions would most likely suggest SSB and catch levels closer to those of scenarios S1 to S3 after they have reached F_{MSY}. STECF therefore stresses that the most critical differences lie in the various paths to reach F_{MSY} in the short-term, more than in the simulated developments after 2025.

STECF notes that the stock-recruitment relationships parameterized over the entire historical period mean that the recruitment time series simulated in the runs are rather overestimated compared to the recent low average, especially for anchovy (Figure 1). For that stock, the results are robust in terms of comparison of scenarios with each other, but they represent an optimistic projection. A continued low recruitment will lead to higher F values and longer time to recovery. Consequently, STECF requested additional MSEs with low recruitment OMs (parameterized on the average over the last five years), which were run after the completion of the ad-hoc report. Results for anchovy are included in this response, while results for sardine are close to those obtained with the long-term average and are not presented here except for the risk table (Table 1).

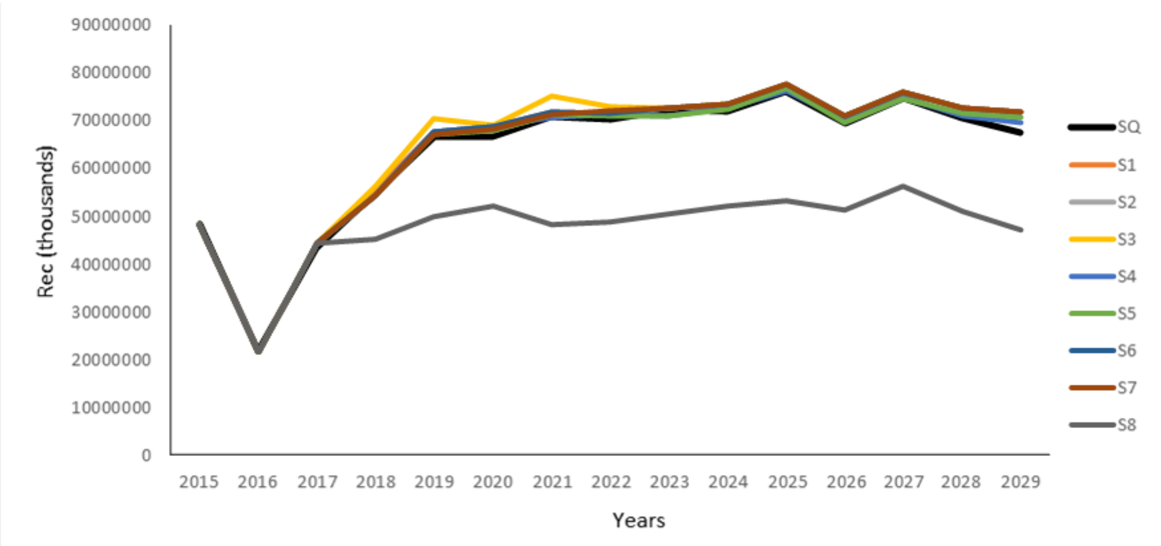

Figure 1: Median value of recruitment for anchovy, OM1, 2015-2030. Black bold line: Status quo F (F2016). Coloured lines: scenarios S1 to S8. Scenario S9 not shown (crashed stock).

The median results have been compiled and compared for the baseline populations (with maturity and natural mortality parameters as used in STECF PLEN 17-03 and STECF EWG 17-09) (Figure 2: Sardine OM5, Figure 3: Anchovy OM1).

These lines are only the middle value across 250 iterations, but the spread of results around this median can be quite large depending on year-to-year recruitment variability. The detailed results including variability (confidence intervals) across all scenarios and OMs are provided in the ad-hoc contract report.

Finally, STECF notes that the MSEs here only include variability in a few biological parameters (recruitment, maturity, natural mortality). Other important sources of uncertainty could not be accounted for in the timeframe of this request, and in particular the assessment uncertainty (imprecise stock assessment) and implementation error (management decisions imperfectly implemented). There are also indications of changes in growth and condition for small pelagics in the Mediterranean Sea (van Beveren et al., 2014), which may play a role in future stock dynamics. Accounting for these would not affect the relative performance of the management strategies compared to each other, but would widen the confidence interval and increase risks.

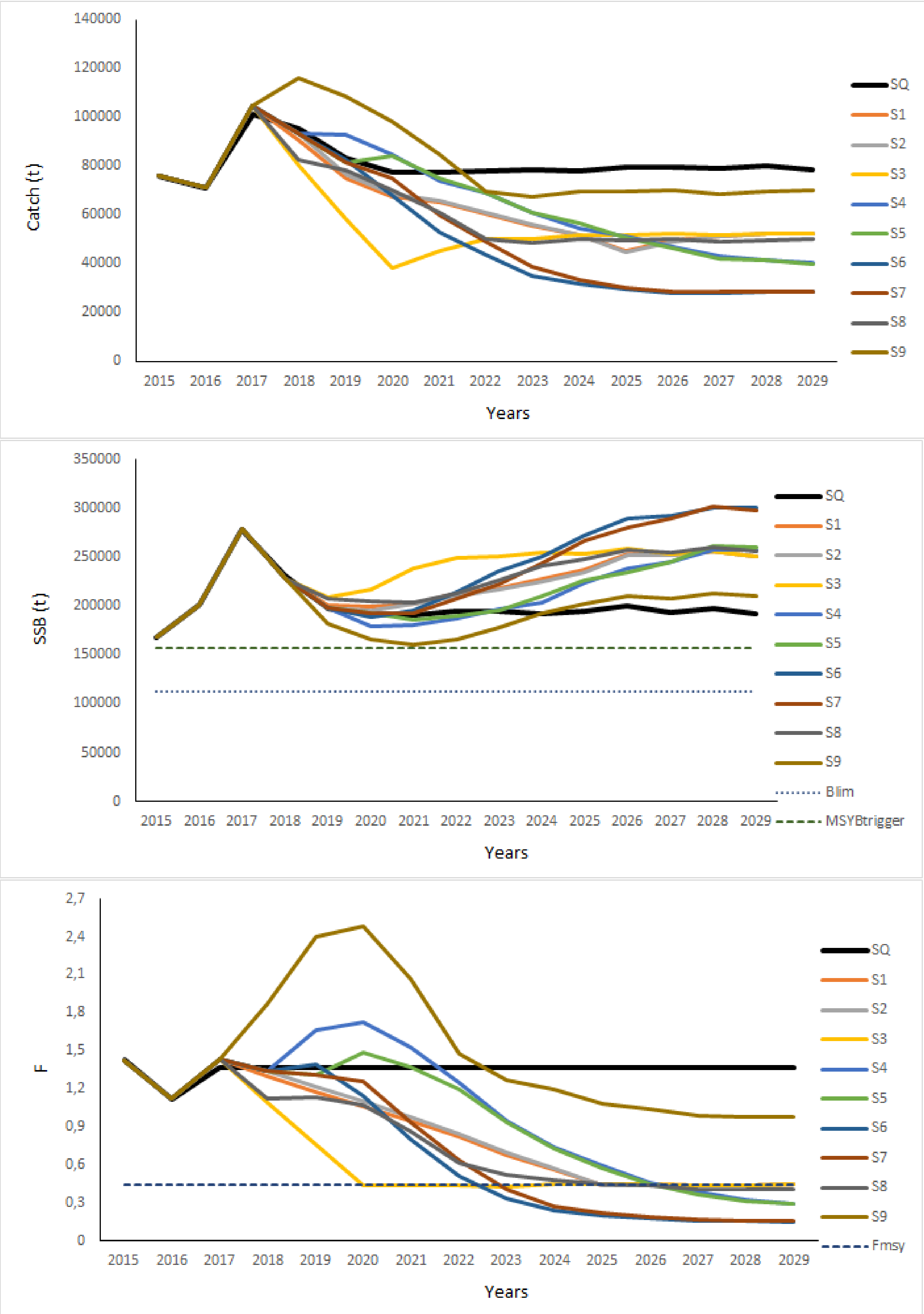

Figure 2: Sardine (OM5). Median value of catch (t), Spawning stock biomass (t) and fishing mortality F 2015-2030. Black bold line: Status quo F (F2016). Coloured lines: scenarios S1 to S9.

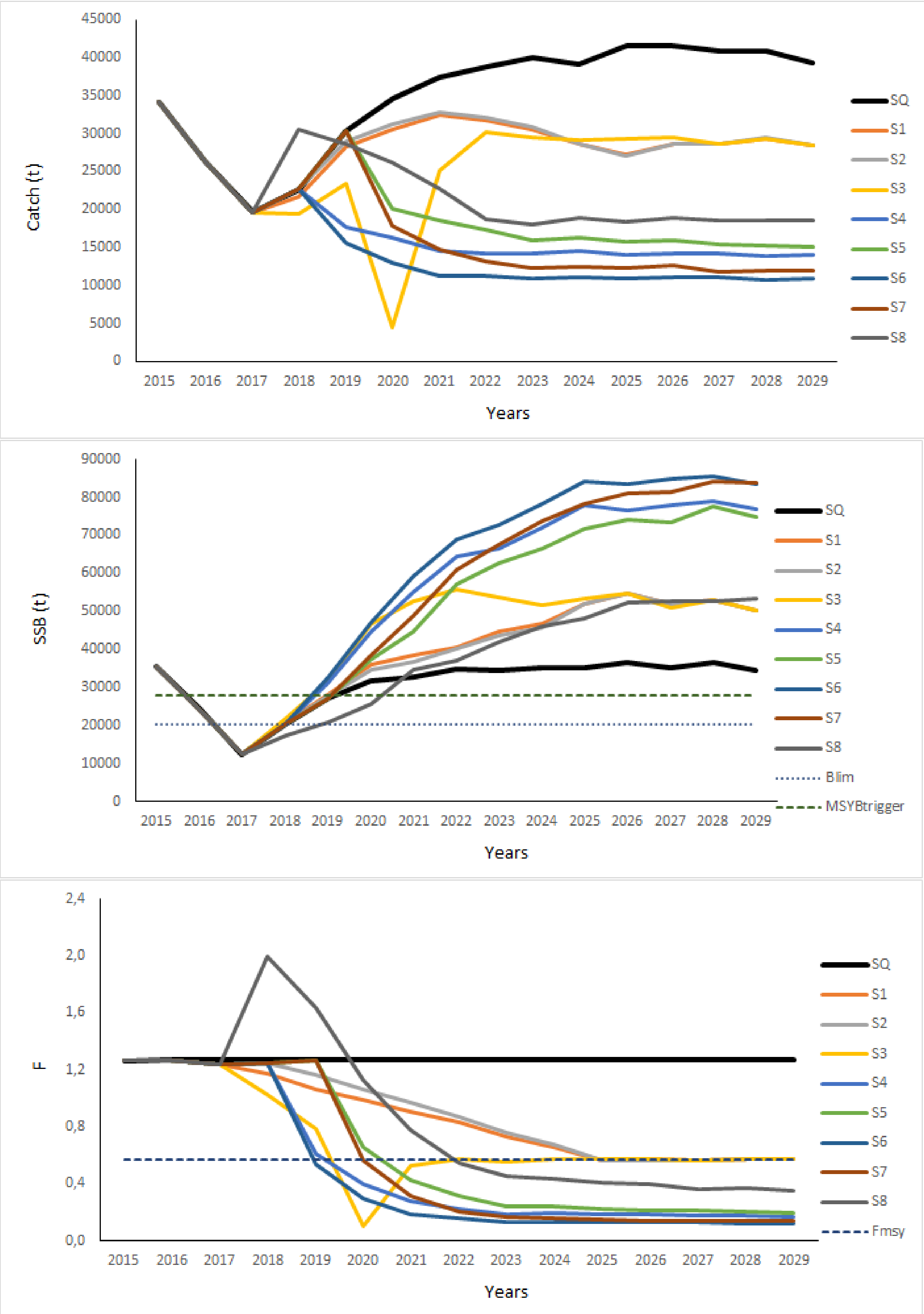

Figure 3: Anchovy with mat age 0 = 0 (OM1). Median value of catch (t), Spawning stock biomass (t) and fishing mortality F 2015-2030. Black bold line: Status quo F (F2016). Coloured lines: scenarios S1 to S8. Scenario S9 not shown (crashed stock).

STECF notes that the various HCRs provide very different outcomes over the short- medium term. For both stocks, status quo fishing mortality is the scenario that results in the lowest levels of biomass, on average just above MSY $B_{trigger}$ but with rather high probabilities of falling below it.

For sardine (Figure 2), all scenarios except S3 and S9 indicate that the transition period 2018-2022 will maintain rather low biomass levels, until the reduction of catches and fishing mortality start showing a positive effect on the stock. Nevertheless, the risk of falling below B_{lim} remains low for all years and scenarios, even at recent recruitment levels (Table 1). There are as such no clear trade-offs between the various scenarios in the short-term, although scenario S4 is less desirable as it implies further increase of fishing mortality in 2019-2021. For scenarios S6 and S7, the 50% probability (median) of reaching F_{MSY} would occur around 2023; for scenarios S1 and S2 that is only expected to occur around 2025and for scenario S4 and S5 around 2026. After 2025, scenarios S1, S2, S3, S5 and S8 provides rather similar outcomes, while scenarios S6 and S7 provide lower catch and higher SSB levels because catches are assumed to keep decreasing even after F_{MSY} is reached. STECF notes also that only scenario S3 complies with the CFP objective of reaching F_{MSY} by 2020. In this scenario, median sardine catches would not fall below around 40.000 t (which correspond to the catch level prior to 2010), though with a lowest confidence interval down below 30 000 t around 2020-2021.

For anchovy (Figure 3), and accounting for long-term average recruitment (optimistic projection), all scenarios induce catch levels way below the F status quo scenario after 2019. Results for S9 are not shown as they indicate an early collapse; and this scenario is also unlikely for anchovy given the smaller contribution of anchovy in the combined pelagic fishery compared to sardine. The scenario S8 is not advisable, as it induces further increases of fishing mortality until 2021. In the short-term, there are important differences in the results produced by the other scenarios, with scenarios S1 and S2 maintaining the highest levels of catches with limited reductions in fishing mortality and biomass increases. In these scenarios, F_{MSY} is expected to be reached around 2025. All other scenarios induce lower catches and higher biomass, of varying degree, with F_{MSY} being reached on average around 2020-2021.

The risks of falling below MSY $B_{trigger}$ are higher if recruitment remains low (Figure 4 for anchovy). The status quo scenario is not sustainable, with median SSB fluctuating below MSY $B_{trigger}$ (B_{pa}) and high risks of falling below B_{lim} (Table 2). Scenarios S3, S4 and S6 would bring the median SSB above MSY $B_{trigger}$ in 2019, while scenarios S1, S2, S5 and S7 would postpone it until 2020-2021. In terms of low risks (less than 5% risk of SSB falling below B_{lim}), S3 would achieve it in 2021, S6 in 2022, and all other scenarios in 2024 or beyond.

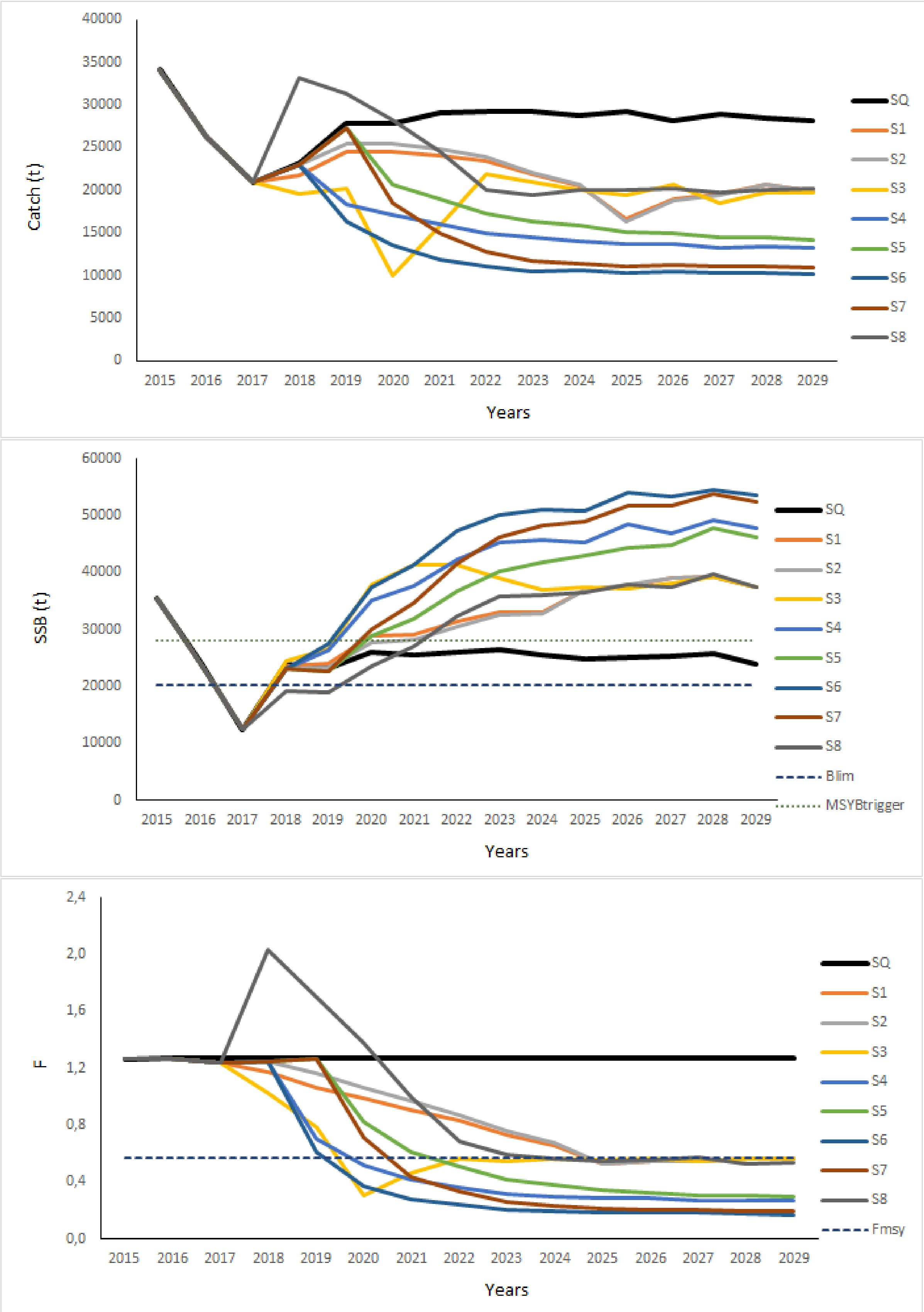

Figure 4: Anchovy with mat age 0 = 0 and low recruitment (OM1lowR). Median value of catch (t), Spawning stock biomass (t) and fishing mortality F for anchovy, OM1, 2015-2030. Black bold line: Status quo F (F2016). Coloured lines: scenarios S1 to S8. Scenario S9 not shown.

Table 1. Sardine with low recruitment (OM5lowR). Risk of falling below B_{lim} per year and scenario. Risk higher than 5% is highlighted in grey

year	SQ	S1	S2	S3	S4	S5	S6	S7	S8	S9
2016	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2
2017	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8
2018	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
2019	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1,2
2020	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1,6
2021	0,0	0,0	0,0	0,0	2,0	1,2	0,8	0,8	0,0	0,4
2022	0,0	0,0	0,0	0,0	3,6	2,4	1,2	0,4	0,0	1,6
2023	0,0	0,0	0,0	0,0	2,4	0,8	0,0	0,0	0,0	0,0
2024	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
2025	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
2026	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
2027	0,0	0,0	0,0	0,0	0,4	0,0	0,0	0,0	0,0	0,0
2028	0,0	0,0	0,0	0,0	0,4	0,0	0,0	0,0	0,0	0,0
2029	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Table 2. Anchovy with mat age 0 = 0 and low recruitment (OM1lowR). Risk of falling below B_{lim} per year and scenario. Risk higher than 5% is highlighted in grey.

year	SQ	S1	S2	S3	S4	S5	S6	S7	S8	S9
2016	22,4	22,4	22,4	22,4	22,4	22,4	22,4	22,4	22,4	22,4
2017	80,8	80,8	80,8	80,8	80,8	80,8	80,8	80,8	80,8	80,8
2018	35,2	33,2	35,2	29,2	35,2	35,2	35,2	35,2	53,2	89,6
2019	35,2	29,6	32,0	20,0	27,6	36,4	24,4	36,4	52,4	96,8
2020	27,2	21,2	22,4	5,6	17,6	24,0	11,2	21,6	39,2	92,4
2021	29,2	21,2	23,6	2,0	14,0	22,0	8,0	16,4	32,8	94,4
2022	32,8	18,0	18,8	1,2	10,8	16,8	4,0	7,2	22,0	89,2
2023	29,6	14,0	15,2	2,8	10,0	12,4	2,8	6,0	18,0	90,4
2024	30,0	8,8	8,4	4,4	6,8	9,2	1,6	1,6	13,6	90,4
2025	30,8	4,4	4,4	2,4	3,2	5,6	0,8	2,0	13,6	91,2
2026	28,0	2,4	2,0	2,4	2,0	6,0	0,8	2,0	11,2	89,2
2027	28,0	3,6	3,6	4,4	1,6	4,8	1,2	0,4	12,4	88,8
2028	33,2	2,8	2,8	3,2	2,4	3,6	0,8	1,2	11,2	89,2
2029	29,6	4,0	4,0	4,0	2,0	2,8	0,8	0,8	8,8	92,0

STECF conclusions

MSE have been performed for anchovy and sardine in the Adriatic, investigating several scenarios for reaching F_{MSY} no later than 2025 under various assumptions of biological parameters (recruitment, maturity, natural mortality). These scenarios highlight the necessary trade-offs between maintaining high catches and insuring low risks of biomass falling below B_{lim}.

The MSE results show outcomes of the various scenarios that are more contrasted for anchovy than for sardine, both in the short and medium-term.

All management scenarios include some reductions of catches and fishing mortality which induce rapid increases in biomass; however, some scenarios imply some further increase of fishing mortality in the short-term, which is not advisable.

STECF raises concerns on the sensitivity of the risk estimates to the choice of maturity parameter for anchovy, which indicates that the current B_{lim} proposed for anchovy with mat=0.5 might not be fully appropriate. STECF concludes that biomass reference points with the new maturity scale should be reconsidered.

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ANNEX I

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Request for services – 1744 – STECF Ad hoc contract on Adriatic small pelagic stocks

Final Report

10th January 2017

Prepared by

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1. Background

The EC has launched the proposal for an EU MAP on the Adriatic small pelagic stocks. In the MAP ANNEX I and II there are respectively the target fishing mortality F_{MSY} ranges and conservation reference points ($MSYB_{trigger}$ and B_{lim}, B_{pa}) for sardine and anchovy. These values were derived from STECF 15-14 (2015a) and are now outdated by revised input data and consequent new assessments. Additionally, the framework for proposing a target fishing mortality has changed from an F_{MSY} computed in EqSIM to a Patterson exploitation rate E = 0.4. (STECF, 2017a)

The MAP proposal is currently in discussion with the European Parliament and the Council. STECF PLEN 17-03 (STECF, 2017a) evaluated both the new assessments of anchovy and sardine in GSA 17-18 and proposed F and B reference points based on a target F that is a proxy of Patterson E = 0.4. An additional scenario is accounting for a different maturity at age 0 (maturity = 0.5 instead of 0) and corresponding reference points. The proposed reference points by STECF PLEN 17-03 are summarized in Table 3.1.

As the above mentioned stock assessments and STECF advice have significantly changed the advice on which the MAP proposal has been built, an additional management strategy evaluation (MSE) work to evaluate alternative scenarios for managing these stocks in the short and medium term needed to be carried out through an ad hoc contract, with technical support from JRC.
The objective of this ad hoc contract (ToR 2) is to build medium term forecast scenarios according to the proposed reference points and to different timings for achieving the F_{MSY} proxy with associated risk.

The work presented here is the result of a MSE for small pelagic fisheries in the Adriatic Sea requested by the STECF PLEN 17-03 (STECF, 2017a). This document contains a description of the MSE models and the results of the simulations carried out based on the assumptions, reference points and scenarios agreed during the STECF PLEN 17-03.

2. Terms of Reference (ToR 2)

For the stocks of anchovy (according to maturity at age0 set to 0 and 0.5) and sardine in the Adriatic Sea, it is requested to evaluate in an MSE framework the sustainability of the management scenarios described below, considering the HCR parametrized by STECF PLEN 17-03 (STECF, 2017a), and taking into account recruitment variability from ToR 1 and sensitivity to natural mortality assumptions. The methodologies used in other MAPs evaluated by STECF will be followed.
The proposed management scenarios are the following:
Time limit: 2030
The different scenarios should be compared with a scenario of fishing at F status quo (average F_{bar} of the last three years).
Tactics:

- linear reduction in F up to years 2020 or 2025 starting in 2019 and 2020;
- catch reduction of 10% or 20% per year starting in 2019 and 2020 until reaching MSY;
- HRV scenario: in 2018 the catch limit for small pelagics shall be set at the level of catch in 2014; starting from 2019, catch limits for small pelagics shall be gradually reduced each year by 5 % in comparison to the previous year until 2022.

3. Methodology

Management Strategy Evaluation (MSE) is widely considered to be the most appropriate way to evaluate the trade-offs achieved by alternative management strategies and to assess the consequences of uncertainty for achieving management goals (Punt et al., 2014). MSE has started to be used in the Mediterranean context within the framework of STECF and GFCM expert groups on stock assessment.

MSE uses simulation testing to determine how robust management strategies are to measurement and process error, and to model uncertainty (Smith 1994). In practice, data are sampled from the operating model to mimic collection of fishery dependent data and research surveys (including variability). These data are used in the assessment model. Using assessment results, the HCR is applied and a management action is determined. According to the management measure set, new catches are estimated and fed again into the operating model. At the end of all the simulations, estimates of the main stock variables and of the catches (given the application of the HCR are available) are provided together with the associated uncertainty.

For the purpose of this work, a single species and single fleet MSE was applied to both anchovy and sardine in GSAs 17-18. Therefore, the two species were treated separately, assuming no interactions between them. A similar approach was used in previous MSE simulations on anchovy and sardine in the Adriatic Sea (GFCM, 2017).

The biological operating model (OM) for the MSE was conditioned using the assessment results from the assessment models (SAM) for sardine and anchovy performed at the STECF EWG 17-09 (STECF, 2017b). For anchovy, an alternative assessment was carried out by the EWG and GFCM WGSASP using maturity at age 0 set to 0.5. The reference points proposed (Table 1) are those determined during the STECF EWG 17-09 and revised by STECF PLEN 17-03.

Table 3.1. Reference points for anchovy and sardine in GSAs 17-18.

Stock	Reference point	Value	Technical basis
anchovy in GSA 17-18 (maturity at age0 = 0)	B_{lim}	20155 t	B_0 * 0.2
anchovy in GSA 17-18 (maturity at age0 = 0)	B_{pa}, MSY $B_{trigger}$	28007 t	B_{lim}*exp(1.645*0.2)[1]
anchovy in GSA 17-18 (maturity at age0 = 0)	F_{MSY}	0.57	E = 0.4
anchovy in GSA 17-18 (maturity at age0 = 0.5)	B_{lim}	32 177 t	B_0 * 0.2
anchovy in GSA 17-18 (maturity at age0 = 0.5)	B_{pa}	44712 t	B_{lim}*exp(1.645*0.2)[1]
sardine in GSA 17-18	B_{lim}	112922 t	B_0 * 0.2
sardine in GSA 17-18	B_{pa} , MSY $B_{trigger}$	156913 t	B_{lim}*exp(1.645*0.2)[1]
sardine in GSA 17-18	F_{MSY}	0.44	E = 0.4

The stock-recruitment relationship used was a segmented regression (hockey stick) with breakpoint at B_{lim} (Figure 3.1).

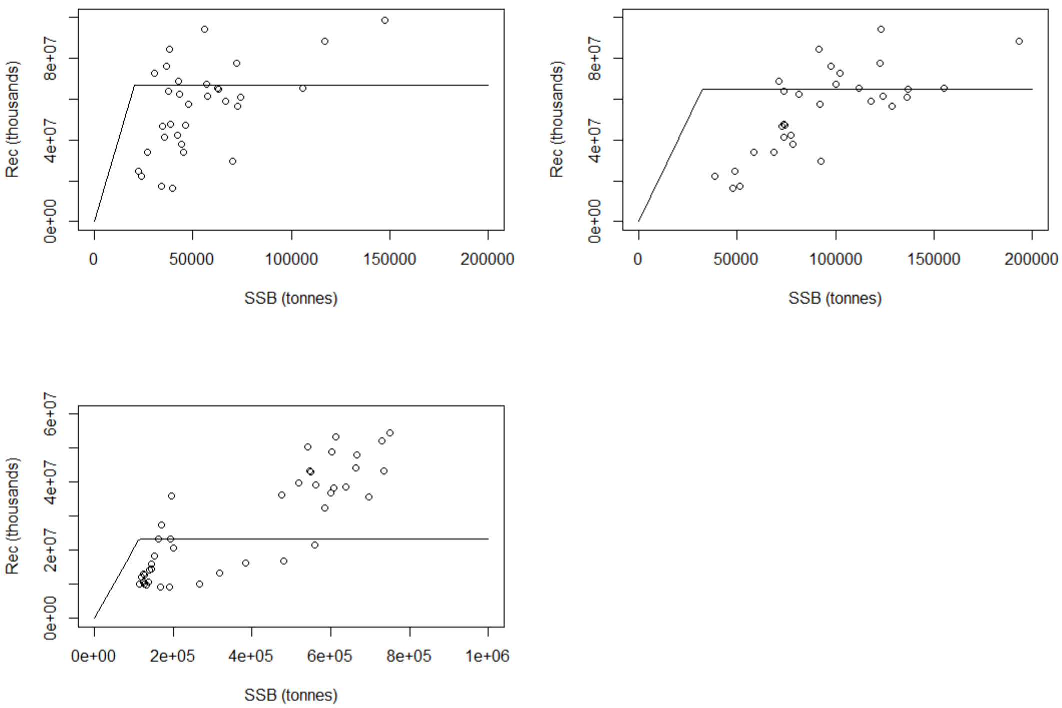

Figure 3.1. Stock-recruitment relationship (hockey stick) in anchovy (top left), anchovy with maturity at age0 set to 0.5 (top right), and sardine (bottom left).

Finally, an alternative natural mortality (constant M set equal to 0.65 for anchovy, and to 0.55 for sardine) was also tested, generating a total of six OMs for the simulations. The reference points for the natural mortality alternatives were recomputed using the same methodology used for the other OMs (ICES, 2015).

To keep consistency across OMs, a4a assessments of the six OMs were run using MCMC to estimate model fit uncertainty (250 iterations). The Assessment for All (FLa4a) stock assessment model in FLR implements a generalized statistical catch-at-age model using ADMB to estimate model parameters. The advantage of this model is that, despite allowing a good flexibility, it requires a relative low number of parameters and a fairly simple formulation (Jardim et al., 2014). The FLa4a models used were set to emulate the results from the validated FLSAM assessment models in terms of SSB, recruitment and fishing mortality for both species (Figures 3.2 and 3.3).

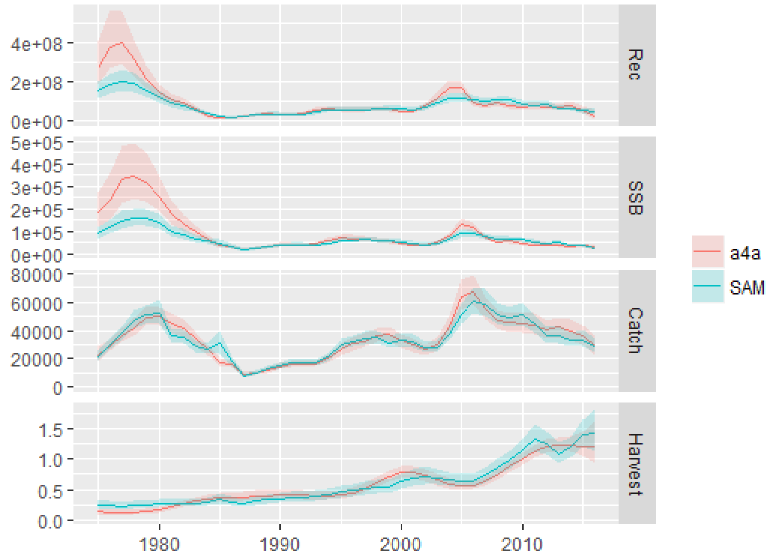

Figure 3.2. Anchovy comparison of estimates from fits: FLSAM (in blue) and FLa4a (in red).

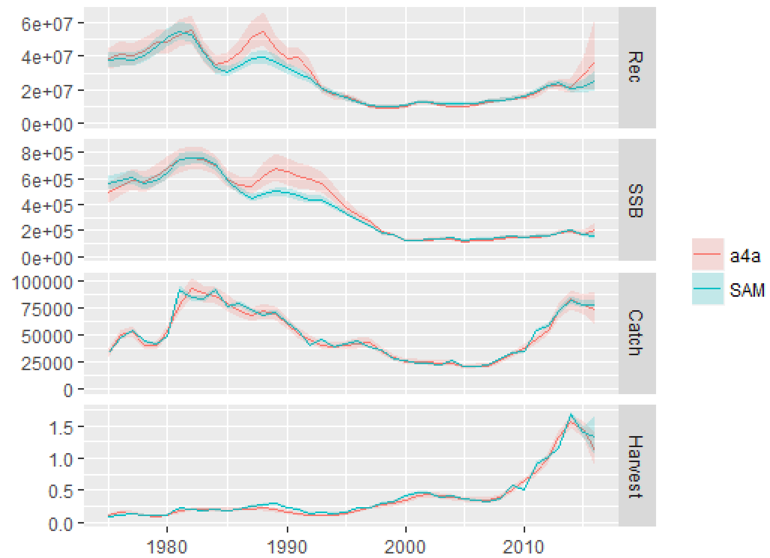

Figure 3.3. Sardine comparison of estimates from fits: FLSAM (in blue) and FLa4a (in red).

The Management Procedure (MP) tested ten management scenarios (including fishing mortality at status quo) agreed during STECF PLEN 17-03, for a total of 60 MSE projections. The linear reduction of F towards F_{MSY} from 2020 to 2020 was not tested, as considered not reliable. Starting from the Croatian proposal, two scenarios were set: a first scenario (S8) in which no shift in the fishing regime will occur, thus the fishery will exploit the two stocks in the same proportion as in the status quo; a second scenario (S9) in which the fishery will target only one of the two stocks. Table 3.2 and Figures 3.4-3.8 summarize the nine management scenarios. All simulations were carried out using the FLR framework (www.flr-project.org/). Each scenario was simulated over a 14-year period (2017 to 2030).

Due to time constraints MSE projections with uncertainty on stock assessment were not run.

Table 3.2. Management scenarios (alternative to Status quo) to be tested.

Stock	Scenario	Tactic	Period
Anchovy (maturity at age0 set to 0)	S1	Linear reduction of F towards F_{MSY} (0.57)	2019-2025
	S2	Linear reduction of F towards F_{MSY} (0.57)	2020-2025
	S3	Linear reduction of F towards F_{MSY} (0.57)	2019-2020
	S4	10% Catch reduction	Start 2019
	S5	10% Catch reduction	Start 2020
	S6	20% Catch reduction	Start 2019
	S7	20% Catch reduction	Start 2020
	S8	Anchovy’s catch in 2018 equal to 2014 catch (33157 t); 5% reduction per year	2018-2022
	S9	Anchovy’s catch in 2018 equal to 2014 total catches (115776 t); 5% reduction per year	2018-2022
Anchovy (constant M)	S1	Linear reduction of F towards F_{MSY} (0.57)	2019-2025
	S2	Linear reduction of F towards F_{MSY} (0.57)	2020-2025
	S3	Linear reduction of F towards F_{MSY} (0.57)	2019-2020
	S4	10% Catch reduction	Start 2019
	S5	10% Catch reduction	Start 2020
	S6	20% Catch reduction	Start 2019
	S7	20% Catch reduction	Start 2020
	S8	Anchovy’s catch in 2018 equal to 2014 catch (33157 t); 5% reduction per year	2018-2022
	S9	Anchovy’s catch in 2018 equal to 2014 total catches (115776 t); 5% reduction per year	2018-2022
Anchovy (maturity at age0 set to 0.5)	S1	Linear reduction of F towards F_{MSY} (0.57)	2019-2025
	S2	Linear reduction of F towards F_{MSY} (0.57)	2020-2025
	S3	Linear reduction of F towards F_{MSY} (0.57)	2019-2020
	S4	10% Catch reduction	Start 2019
	S5	10% Catch reduction	Start 2020
	S6	20% Catch reduction	Start 2019
	S7	20% Catch reduction	Start 2020
	S8	Anchovy’s catch in 2018 equal to 2014 catch (33157 t); 5% reduction per year	2018-2022
	S9	Anchovy’s catch in 2018 equal to 2014 total catches (115776 t); 5% reduction per year	2018-2022
Anchovy (maturity at age0 set to 0.5; constant M)	S1	Linear reduction of F towards F_{MSY} (0.57)	2019-2025
	S2	Linear reduction of F towards F_{MSY} (0.57)	2020-2025
	S3	Linear reduction of F towards F_{MSY} (0.57)	2019-2020
	S4	10% Catch reduction	Start 2019
	S5	10% Catch reduction	Start 2020
	S6	20% Catch reduction	Start 2019
	S7	20% Catch reduction	Start 2020
	S8	Anchovy’s catch in 2018 equal to 2014 catch (33157 t); 5% reduction per year	2018-2022
	S9	Anchovy’s catch in 2018 equal to 2014 total catches (115776 t); 5% reduction per year	2018-2022
Sardine	S1	Linear reduction of F towards F_{MSY} (0.44)	2019-2025
	S2	Linear reduction of F towards F_{MSY} (0.44)	2020-2025
	S3	Linear reduction of F towards F_{MSY} (0.44)	2019-2020
	S4	10% Catch reduction	Start 2019
	S5	10% Catch reduction	Start 2020
	S6	20% Catch reduction	Start 2019
	S7	20% Catch reduction	Start 2020
	S8	Sardine’s catch in 2018 equal to 2014 catch (82619 t); 5% reduction per year	2018-2022
	S9	Sardine’s catch in 2018 equal to 2014 total catches (115776 t); 5% reduction per year	2018-2022
Sardine (constant M)	S1	Linear reduction of F towards F_{MSY} (0.44)	2019-2025
	S2	Linear reduction of F towards F_{MSY} (0.44)	2020-2025
	S3	Linear reduction of F towards F_{MSY} (0.44)	2019-2020
	S4	10% Catch reduction	Start 2019
	S5	10% Catch reduction	Start 2020
	S6	20% Catch reduction	Start 2019
	S7	20% Catch reduction	Start 2020
	S8	Sardine’s catch in 2018 equal to 2014 catch (82619 t); 5% reduction per year	2018-2022
	S9	Sardine’s catch in 2018 equal to 2014 total catches (115776 t); 5% reduction per year	2018-2022

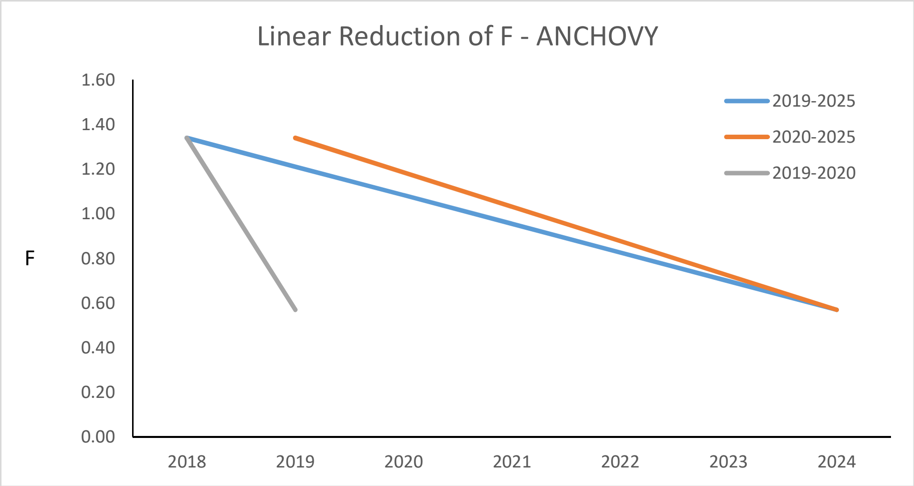

Figure 3.4. Anchovy: management scenarios based on the linear reduction of F.

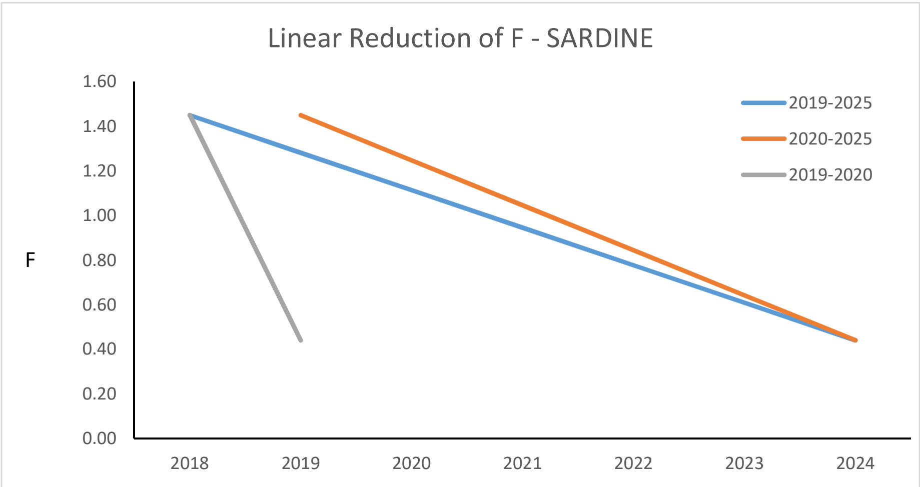

Figure 3.5. Sardine: management scenarios based on the linear reduction of F.

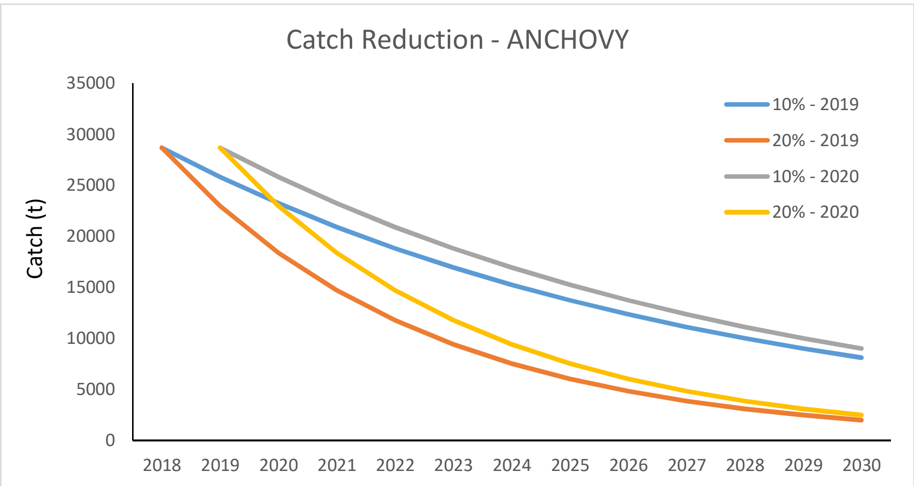

Figure 3.6. Anchovy: management scenarios based on catch reduction.

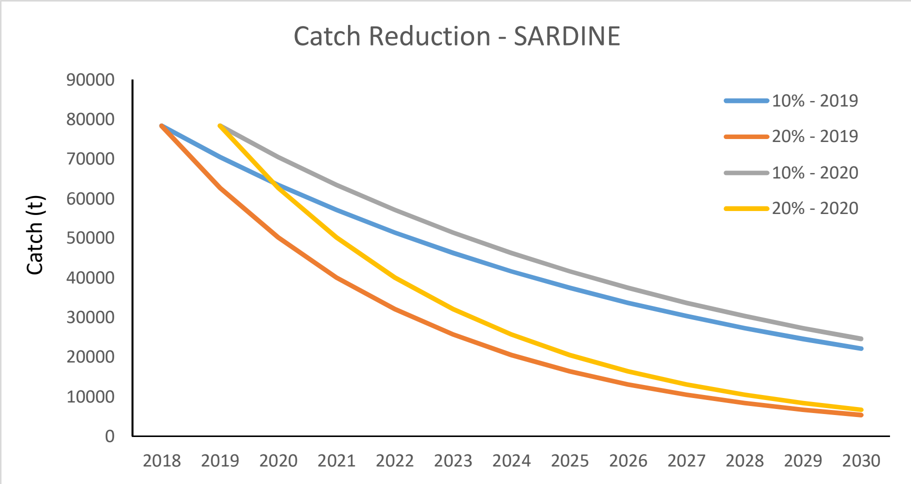

Figure 3.7. Sardine: management scenarios based on catch reduction.

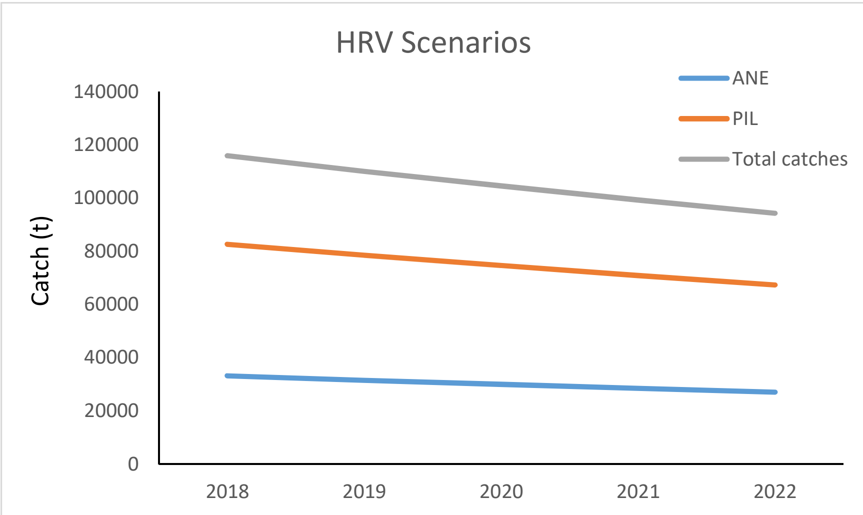

Figure 3.8. Scenarios proposed by Croatia.

4. Results

Section 4.1 shows the results of the MSE projections run without stock assessment on the ten scenarios.

4.1 MSE projections without stock assessment uncertainty

For each of the six OMs investigated, the results of MSE projections without stock assessment uncertainty of the ten management scenarios are summarized in the following paragraphs (4.1.1-4.1.6).

4.1.1 Anchovy in GSAs 17-18

The results of the MSE projections for the anchovy stock with a maturity at age0 set to 0 are shown in the Figures 4.1.1.1-4.1.1.10 and Table 4.1.1.1.

Scenario 3 (linear reduction of F towards F_{MSY} in the period 2019-2020) recovers the stock earlier than the other scenarios, since it is the scenario that reduces fishing mortality faster and earlier. However, Scenario 3 drives F (and catch) to a very low level before reaching F_{MSY}. Scenarios 1, 2, 4, 5, 6 and 7 show intermediate results.

Note that projections of scenarios based on catch reductions end up with fishing mortalities below F_{MSY}. In these scenarios, once F_{MSY} is reached, catches are kept constant for the rest of the forecast, since there were no indications of what management will look like after reaching the objective. Keeping catches at the level when F_{MSY} is reached for the first time, means that catches will be lower than MSY, since the stock is not at its equilibrium level yet, as such generating fishing mortalities lower than F_{MSY}.

Also note that recruitment in the projections is higher than the most recent estimations. This is due to the use of a segmented regression model for recruitment, which assumes average recruitment over a wide range of SSB values. The EWG found a S/R linear model, which shows a decrease of recruitment at low levels of SSB. This effect was not captured by the model used in the projections, and as such the model projections may be optimistic and should be taken with care. This effect is very clear in the Status quo scenario, which seems to recover SSB and catches at high levels of F. This result must be considered as not reliable.

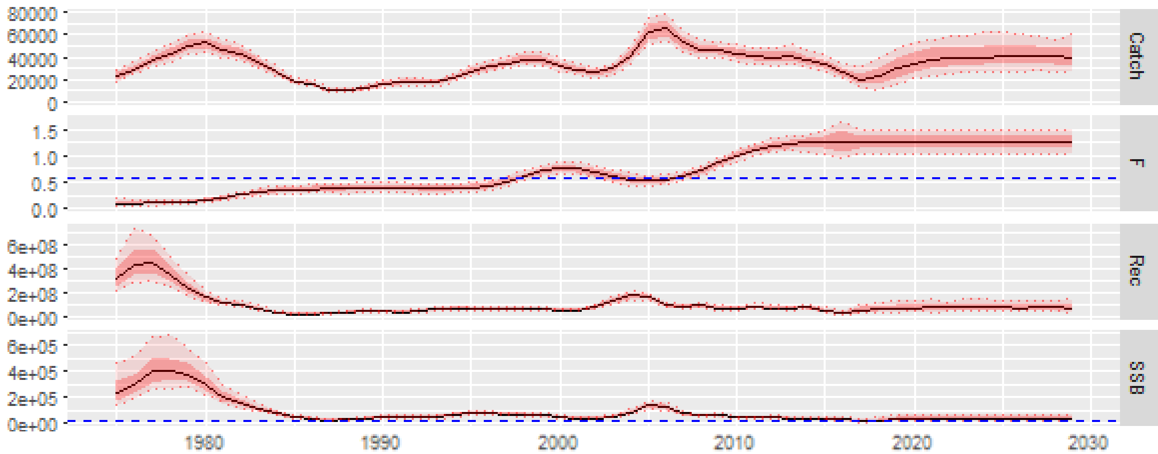

Figure 4.1.1.1. Anchovy: MSE projection (Status quo, mean F_{bar} of the last 3 years, 2014-2016) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (20155 t).

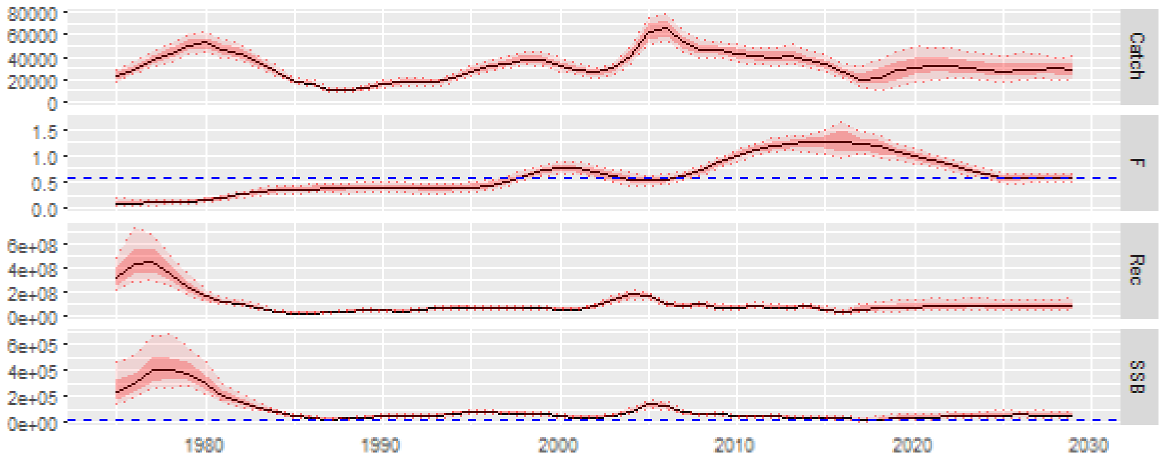

Figure 4.1.1.2. Anchovy: MSE projection (Scenario 1, linear reduction of F towards F_{MSY} in the period 2019-2025) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (20155 t).

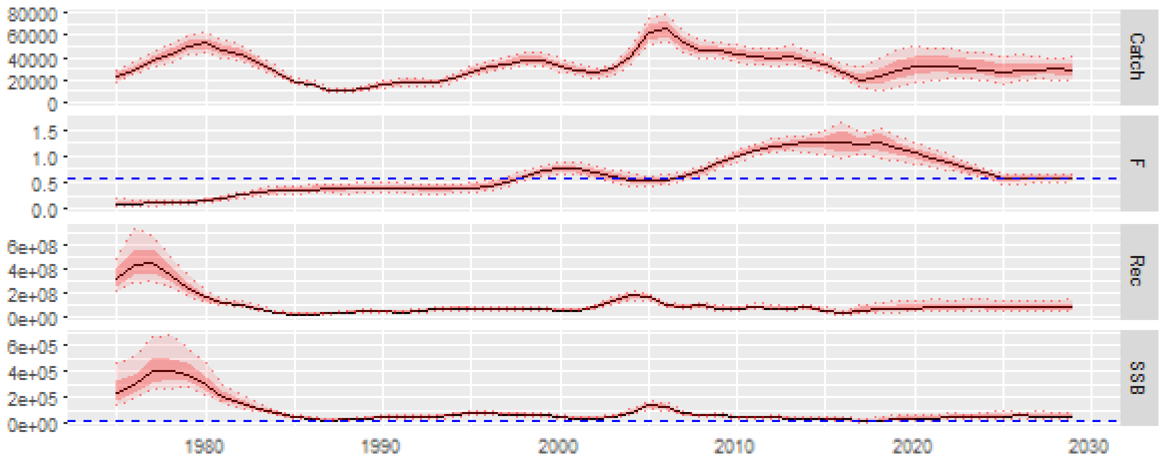

Figure 4.1.1.3. Anchovy: MSE projection (Scenario 2, linear reduction of F towards F_{MSY} in the period 2020-2025) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (20155 t).

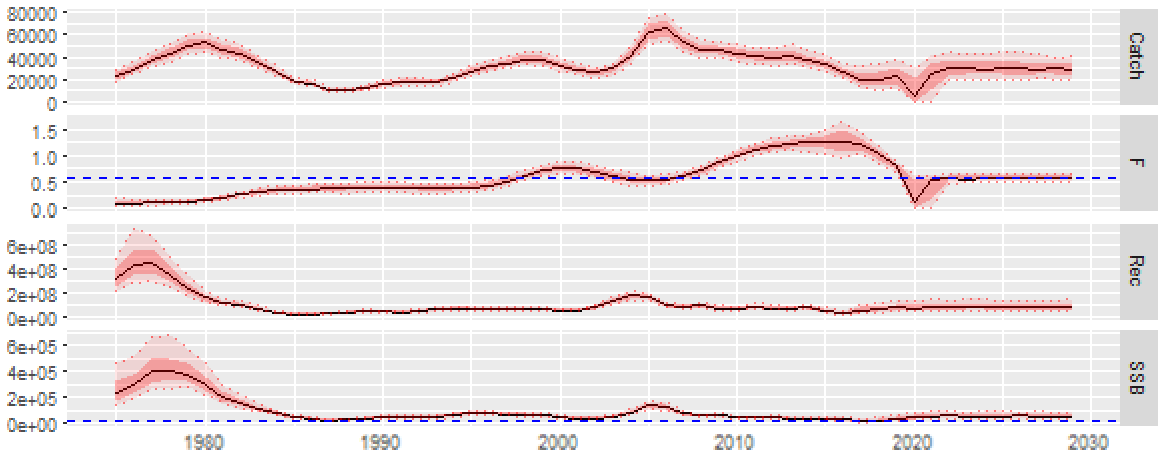

Figure 4.1.1.4. Anchovy: MSE projection (Scenario 3, linear reduction of F towards F_{MSY} in the period 2019-2020) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (20155 t).

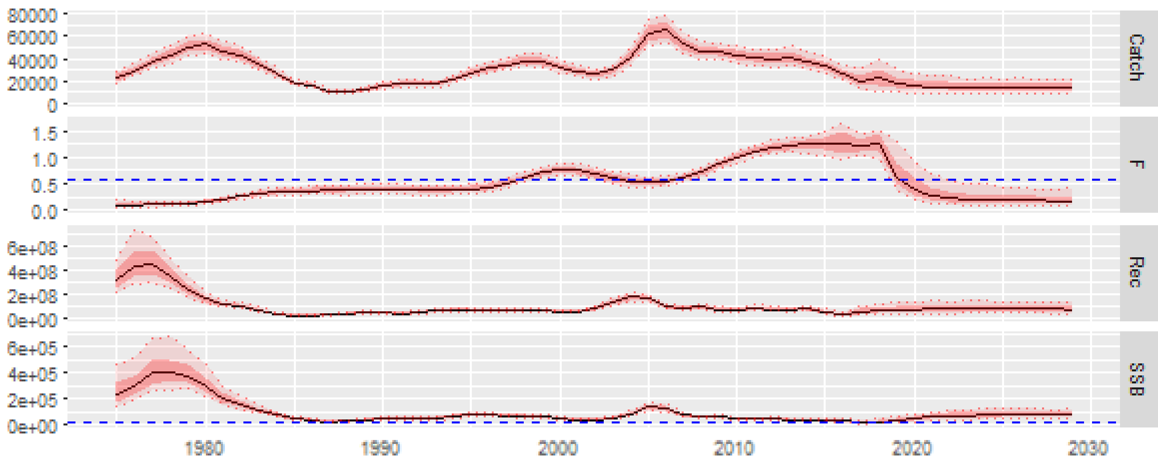

Figure 4.1.1.5. Anchovy: MSE projection (Scenario 4, 10% catch reduction starting in 2019) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (20155 t).

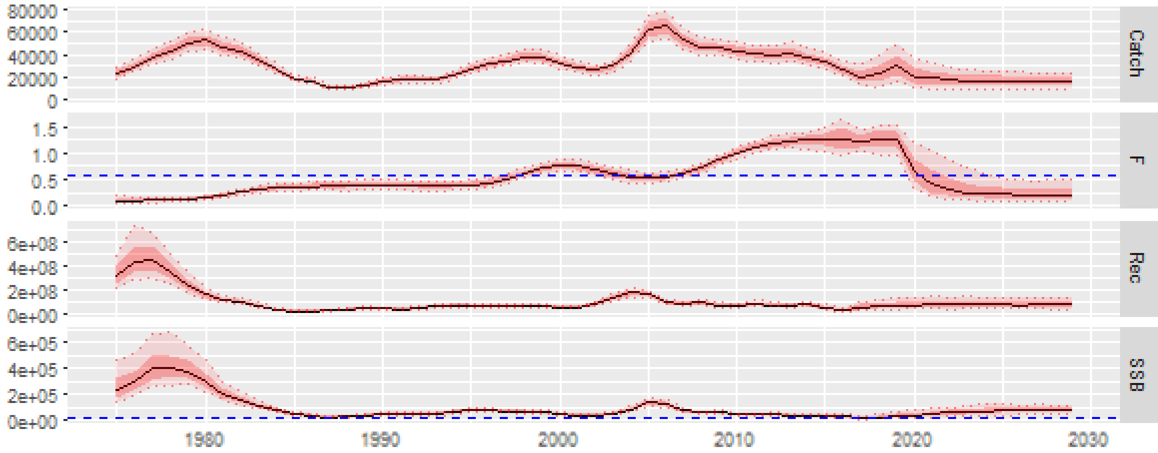

Figure 4.1.1.6. Anchovy: MSE projection (Scenario 5, 10% catch reduction starting in 2020) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (20155 t).

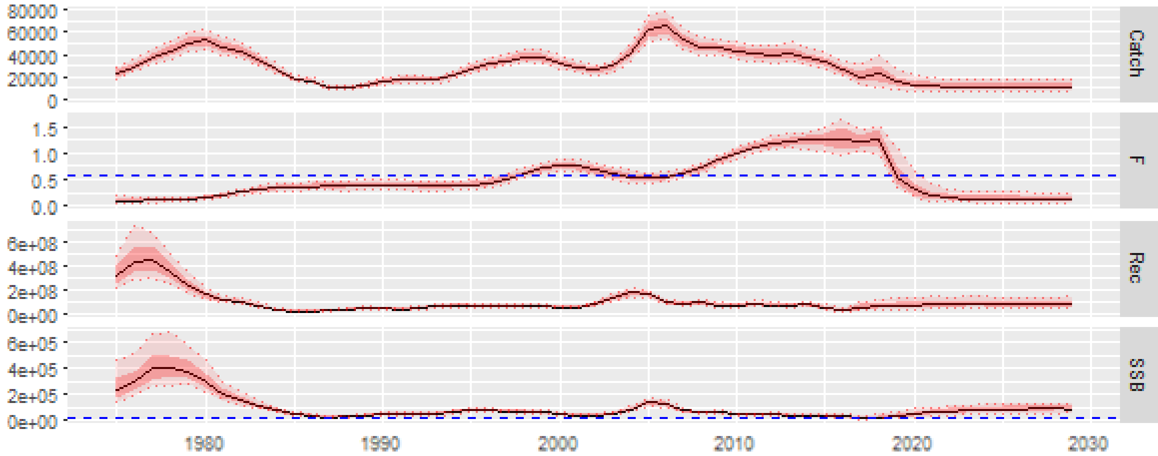

Figure 4.1.1.7. Anchovy: MSE projection (Scenario 6, 20% catch reduction starting in 2019) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (20155 t).

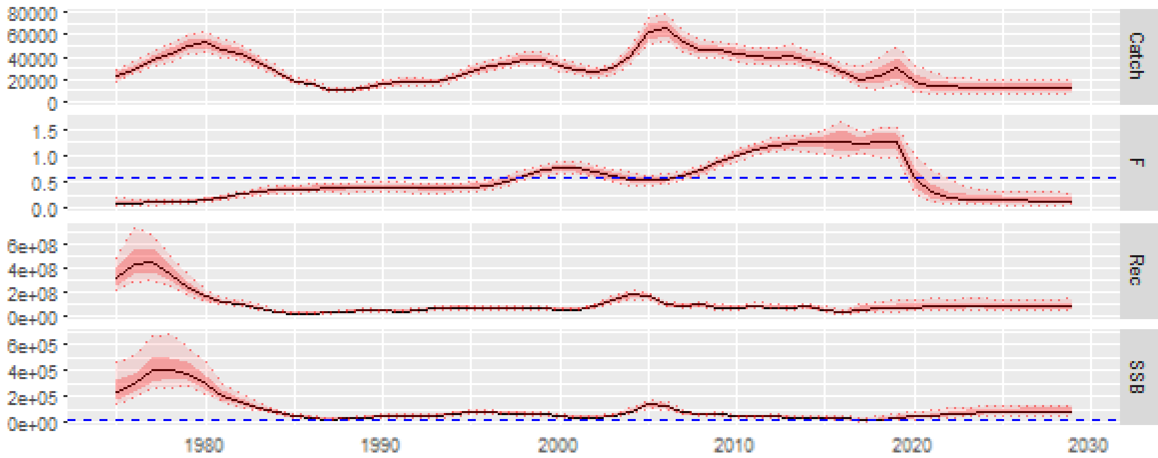

Figure 4.1.1.8. Anchovy: MSE projection (Scenario 7, 20% catch reduction starting in 2020) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (20155 t).

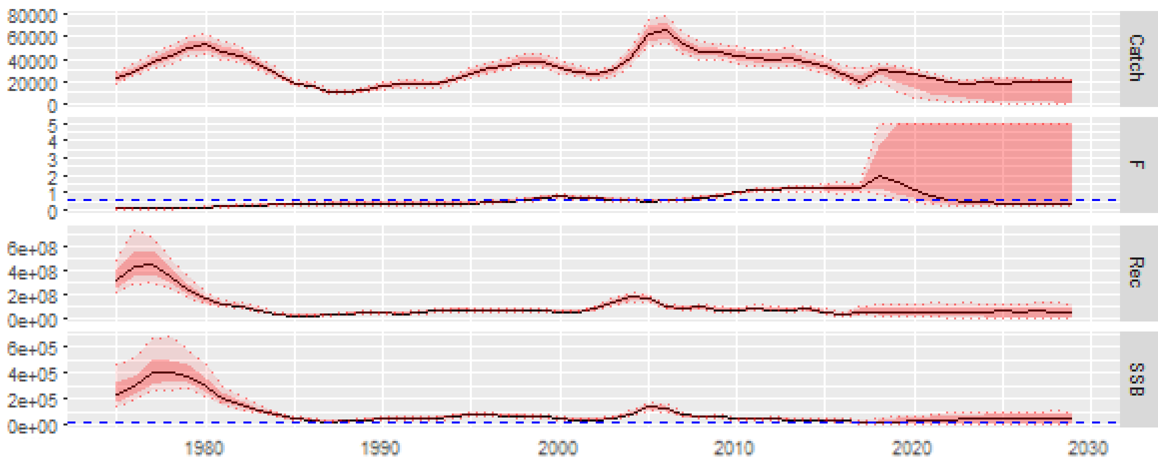

Figure 4.1.1.9. Anchovy: MSE projection (Scenario 8, catch in 2018 equal to catch in 2014, then 5% reduction in 2018-2022) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (20155 t).

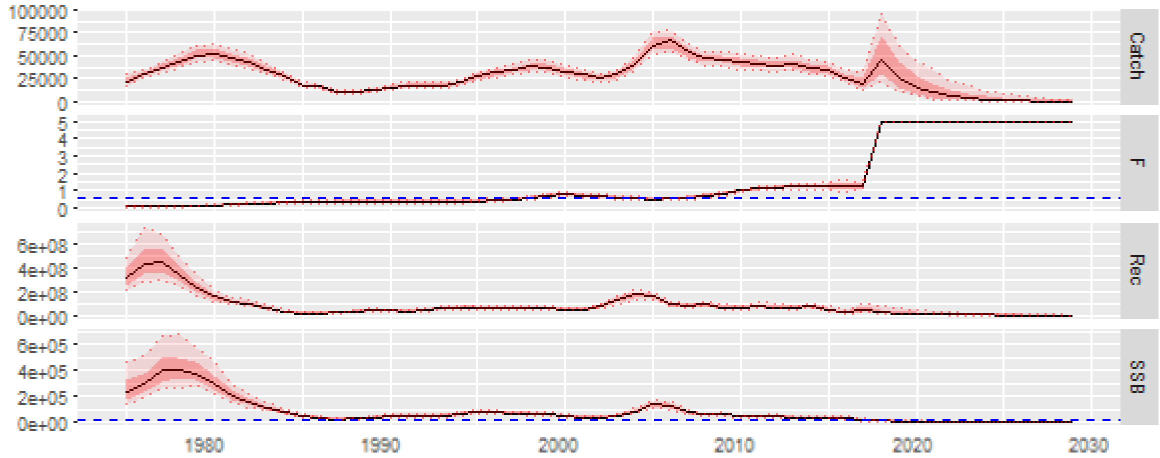

Figure 4.1.1.10. Anchovy: MSE projection (Scenario 9, catch in 2018 equal to total catches in 2014, then 5% reduction in 2018-2022) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (20155 t).

Table 4.1.1.1. Anchovy: probability of SSB falling below B_{lim} by year and Scenario. SQ: Status quo, mean F_{bar} of the last 3 years 2014-2016; S1: linear reduction of F towards F_{MSY} in the period 2019-2025; S2: linear reduction of F towards F_{MSY} in the period 2020-2025; S3: linear reduction of F towards F_{MSY} in the period 2019-2020; S4: 10% catch reduction 2019-2030; S5: 10% catch reduction 2020-2030; S6: 20% catch reduction 2019-2030; S7: 20% catch reduction 2020-2030; S8: catch in 2018 equal to catch in 2014, then 5% reduction 2018-2022; S9: catch in 2018 equal to total catches in 2014, then 5% reduction 2018-2022.

Year	SQ	S1	S2	S3	S4	S5	S6	S7	S8	S9
2016	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4
2017	80.8	80.8	80.8	80.8	80.8	80.8	80.8	80.8	80.8	80.8
2018	50.0	46.8	48.8	45.2	48.8	48.8	48.8	48.8	56.8	88.0
2019	28.8	26.0	28.4	19.2	23.2	29.6	21.6	29.6	48.8	95.2
2020	17.6	10.4	13.6	2.4	11.2	13.2	8.8	12.0	41.6	96.8
2021	14.0	6.0	9.6	0.0	7.2	9.2	4.8	6.8	40.4	98.8
2022	12.4	2.8	4.8	0.0	6.0	6.8	1.6	3.2	37.2	98.0
2023	10.0	2.4	3.6	0.4	3.6	4.0	0.8	0.8	36.4	98.4
2024	10.0	2.0	2.4	0.4	2.0	3.6	0.8	0.8	35.6	98.8
2025	8.8	0.0	0.0	0.0	2.8	4.4	0.0	0.4	35.2	98.4
2026	8.0	0.0	0.0	0.0	2.0	3.2	0.0	0.4	34.4	99.6
2027	9.2	0.4	0.4	0.4	2.4	3.6	0.0	0.4	34.4	99.6
2028	10.4	0.0	0.0	0.0	2.0	2.4	0.0	0.4	33.6	99.2
2029	13.6	0.0	0.0	0.0	2.0	2.8	0.0	0.0	33.6	100.0

4.1.2 Anchovy in GSAs 17-18 (Constant M)

The results of the MSE projections for the anchovy stock with a maturity at age0 set to 0, and a constant natural mortality (M = 0.65) are shown in the Figures 4.1.2.1-4.1.2.10 and Table 4.1.2.1.

These scenarios should be seen as robustness tests of section 4.1.1. The comments presented are also relevant here. Overall, the mis-specification of natural mortality deteriorates the HCR performance. These results would need further exploration to understand which effect is having this negative impact.

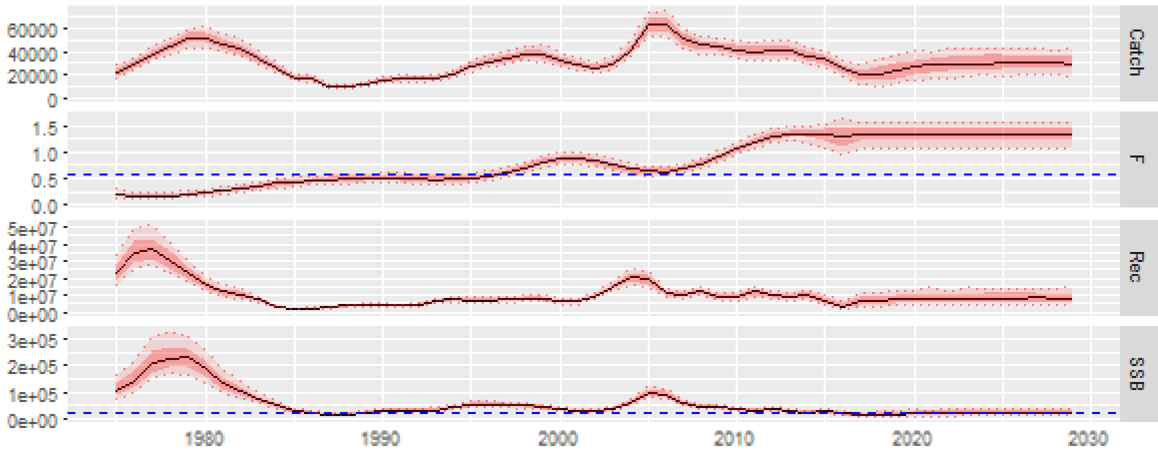

Figure 4.1.2.1. Anchovy (constant M): MSE projection (Status quo, mean F_{bar} of the last 3 years, 2014-2016) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (20155 t).

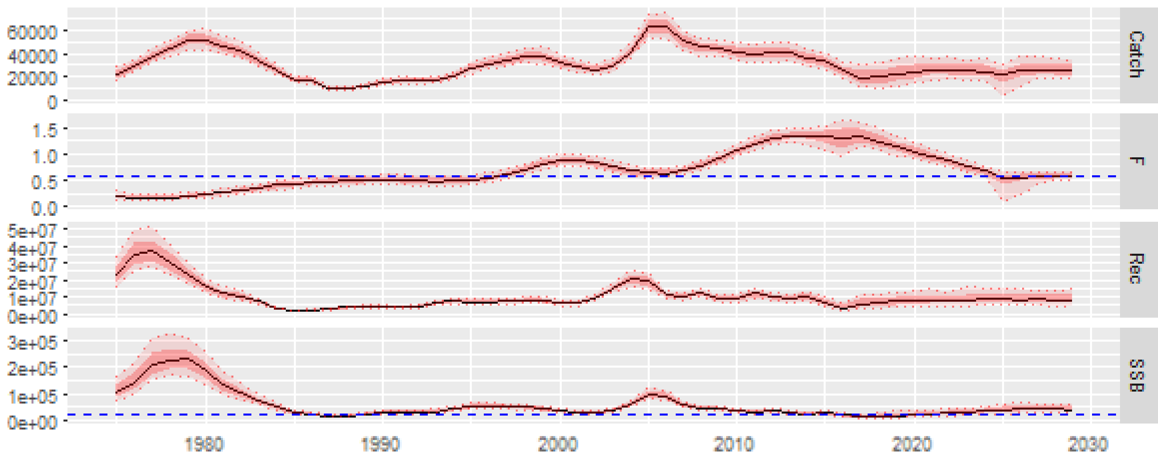

Figure 4.1.2.2. Anchovy (constant M): MSE projection (Scenario 1, linear reduction of F towards F_{MSY} in the period 2019-2025) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (20155 t).

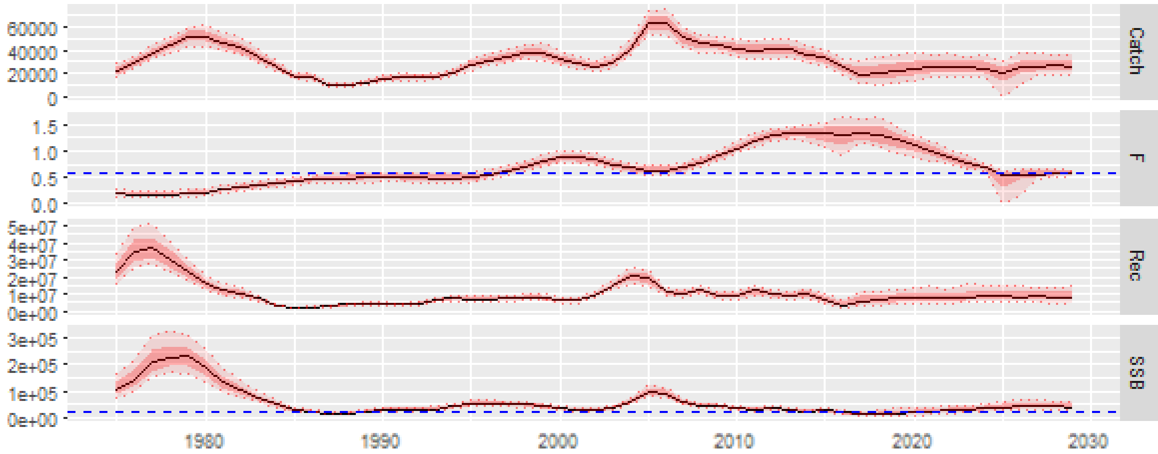

Figure 4.1.2.3. Anchovy (constant M): MSE projection (Scenario 2, linear reduction of F towards F_{MSY} in the period 2020-2025) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (20155 t).

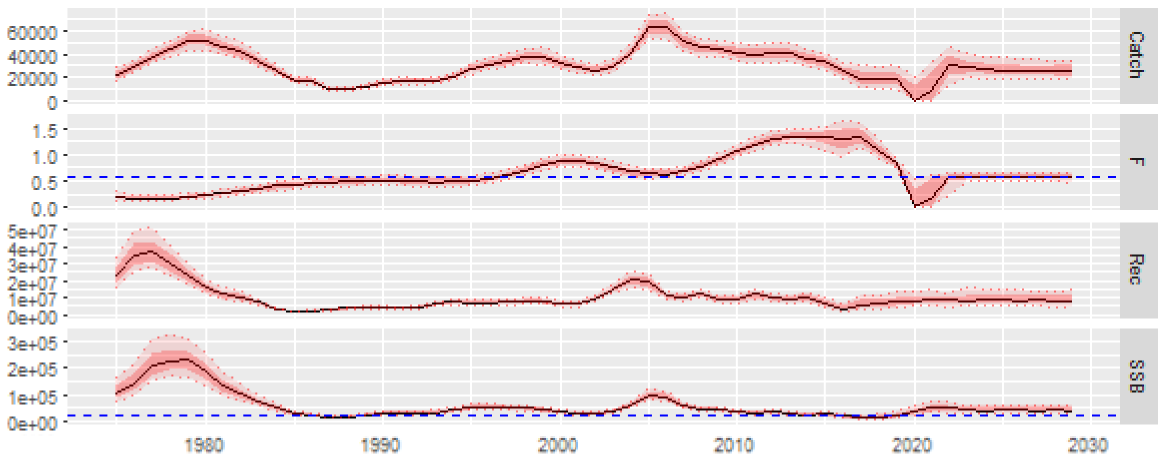

Figure 4.1.2.4. Anchovy (constant M): MSE projection (Scenario 3, linear reduction of F towards F_{MSY} in the period 2019-2020) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (20155 t).

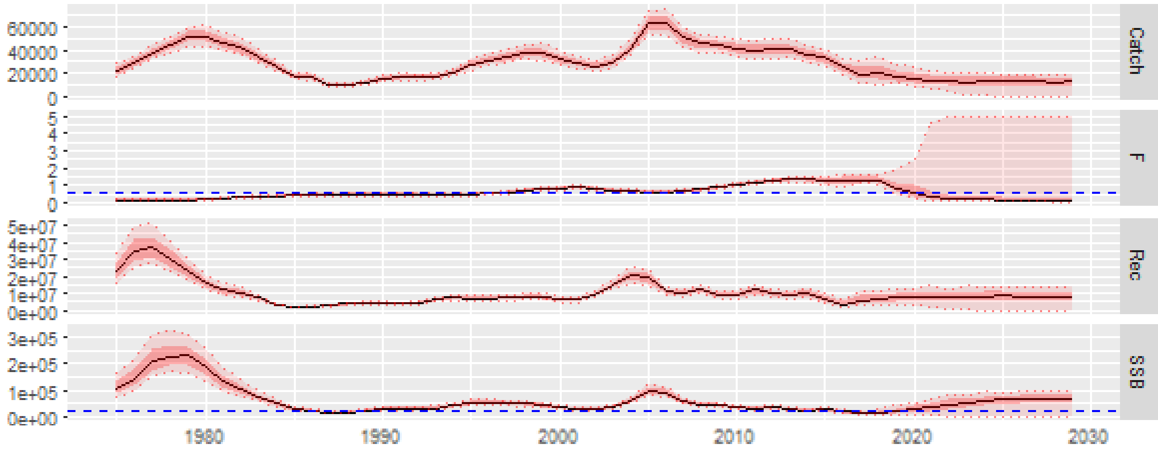

Figure 4.1.2.5. Anchovy (constant M): MSE projection (Scenario 4, 10% catch reduction starting in 2019) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (20155 t).

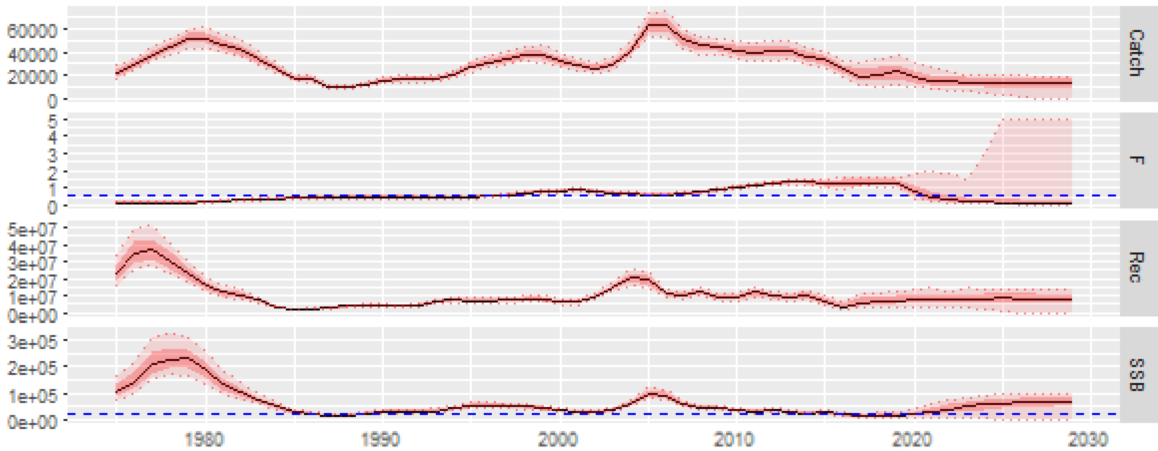

Figure 4.1.2.6. Anchovy (constant M): MSE projection (Scenario 5, 10% catch reduction starting in 2020) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (20155 t).

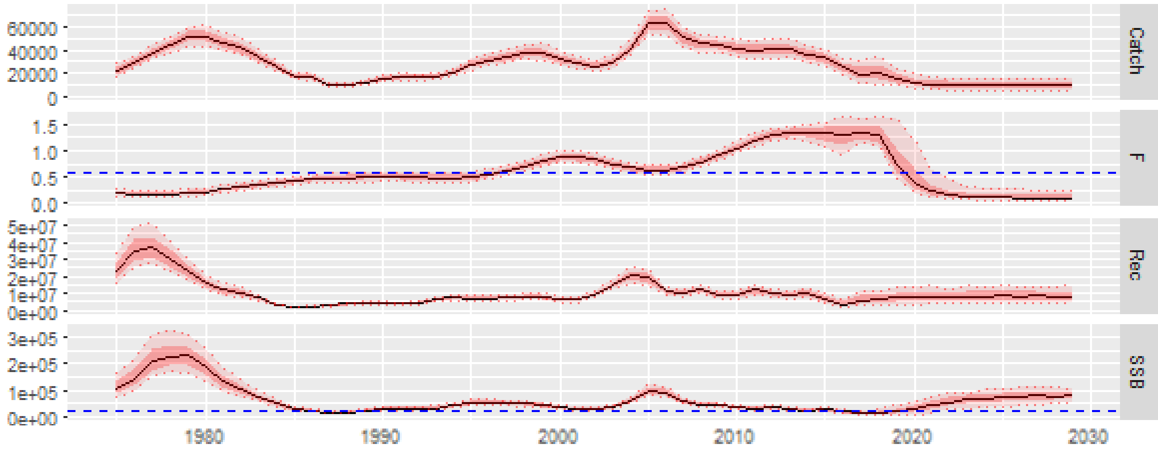

Figure 4.1.2.7. Anchovy (constant M): MSE projection (Scenario 6, 20% catch reduction starting in 2019) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (20155 t).

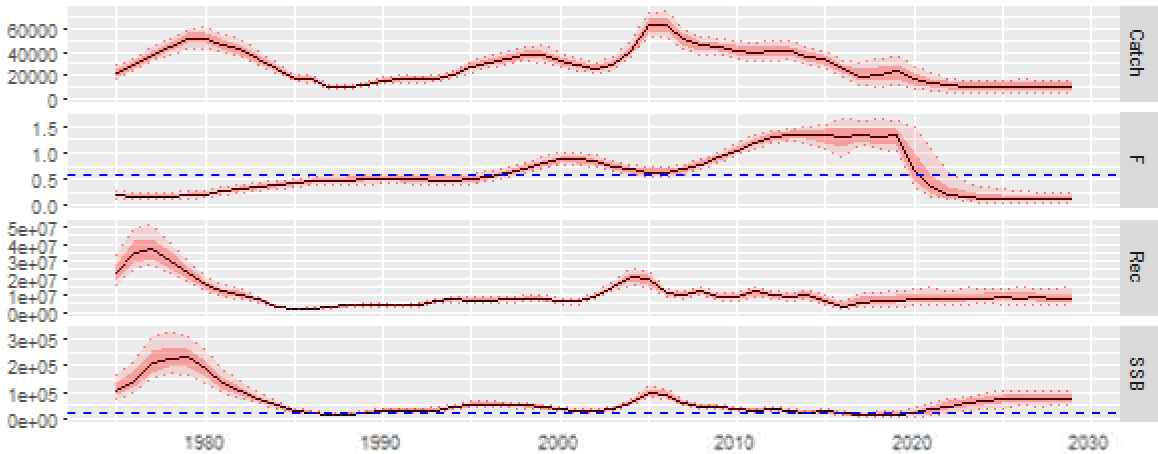

Figure 4.1.2.8. Anchovy (constant M): MSE projection (Scenario 7, 20% catch reduction starting in 2020) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (20155 t).

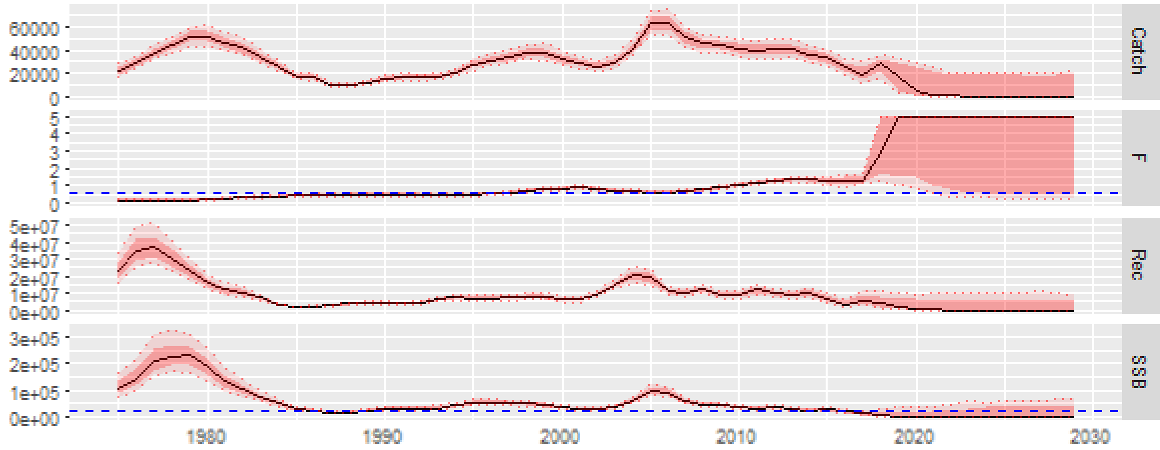

Figure 4.1.2.9. Anchovy (constant M): MSE projection (Scenario 8, catch in 2018 equal to catch in 2014, then 5% reduction in 2018-2022) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (20155 t).

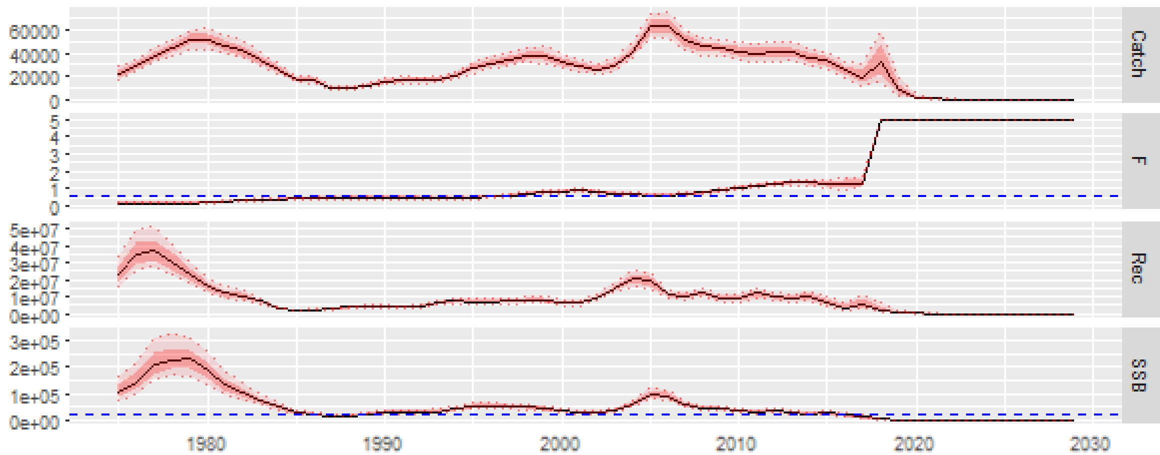

Figure 4.1.2.10. Anchovy (constant M): MSE projection (Scenario 9, catch in 2018 equal to total catches in 2014, then 5% reduction in 2018-2022) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (20155 t).

Table 4.1.2.1. Anchovy (constant M): probability of SSB falling below B_{lim} by year and Scenario. SQ: Status quo, mean F_{bar} of the last 3 years 2014-2016; S1: linear reduction of F towards F_{MSY} in the period 2019-2025; S2: linear reduction of F towards F_{MSY} in the period 2020-2025; S3: linear reduction of F towards F_{MSY} in the period 2019-2020; S4: 10% catch reduction 2019-2030; S5: 10% catch reduction 2020-2030; S6: 20% catch reduction 2019-2030; S7: 20% catch reduction 2020-2030; S8: catch in 2018 equal to catch in 2014, then 5% reduction 2018-2022; S9: catch in 2018 equal to total catches in 2014, then 5% reduction 2018-2022.

Year	SQ	S1	S2	S3	S4	S5	S6	S7	S8	S9
2016	47.6	47.6	47.6	47.6	47.6	47.6	47.6	47.6	47.6	47.6
2017	88.4	88.0	88.0	88.0	88.0	88.0	88.0	88.0	88.0	88.0
2018	64.8	63.6	63.2	59.2	63.2	63.2	63.2	63.2	75.2	98.8
2019	62.8	60.8	62.8	36.8	53.2	64.8	47.2	64.8	77.6	100.0
2020	50.8	34.8	40.0	6.0	27.6	42.0	21.2	38.0	76.8	100.0
2021	46.8	24.0	29.6	0.4	19.6	23.6	13.6	17.2	72.8	100.0
2022	44.8	15.2	18.0	0.0	16.4	18.4	8.8	9.6	72.0	100.0
2023	42.4	7.6	11.6	0.4	13.6	14.0	6.8	6.4	70.4	100.0
2024	38.8	6.0	6.4	1.2	12.4	11.2	6.4	6.0	70.0	100.0
2025	37.2	0.8	1.6	0.0	12.4	11.2	5.6	4.8	69.6	100.0
2026	37.2	0.0	0.0	0.0	11.6	10.8	5.6	4.0	69.6	100.0
2027	39.2	0.4	0.4	0.8	12.0	10.8	5.6	4.0	69.2	100.0
2028	32.0	0.4	0.8	0.4	11.6	10.8	5.6	4.0	69.2	100.0
2029	39.6	0.0	0.0	0.0	11.6	10.8	5.6	4.0	69.2	100.0

4.1.3 Anchovy in GSAs 17-18 (maturity at age0 = 0.5)

The results of the MSE projections for the anchovy stock with a maturity at age0 set to 0.5 are shown in the Figures 4.1.3.1-4.1.3.10 and Table 4.1.3.1.

All the scenarios, with the only exception of Scenario 9, are showing good performance in terms of the probability of SSB falling below B_{lim}.

In these scenarios, the dynamics of the stock were revised although the target fishing mortality was kept the same. This inconsistency was not explored further and, together with the optimistic S/R, may explain the very positive results obtained.

See comments in section 4.1.1.

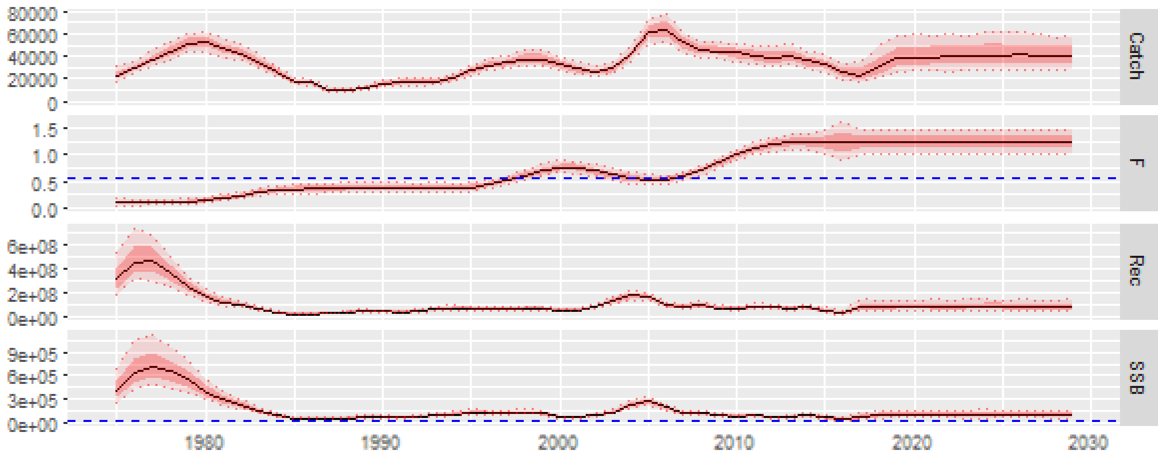

Figure 4.1.3.1. Anchovy (maturity at age0 = 0.5): MSE projection (Status quo, mean F_{bar} of the last 3 years, 2014-2016) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (32177 t).

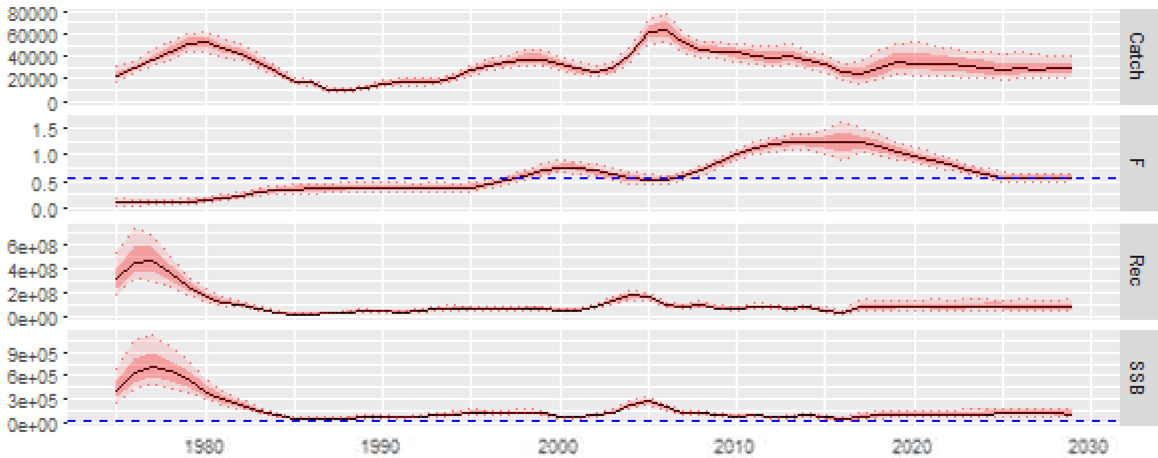

Figure 4.1.3.2. Anchovy (maturity at age0 = 0.5): MSE projection (Scenario 1, linear reduction of F towards F_{MSY} in the period 2019-2025) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (32177 t).

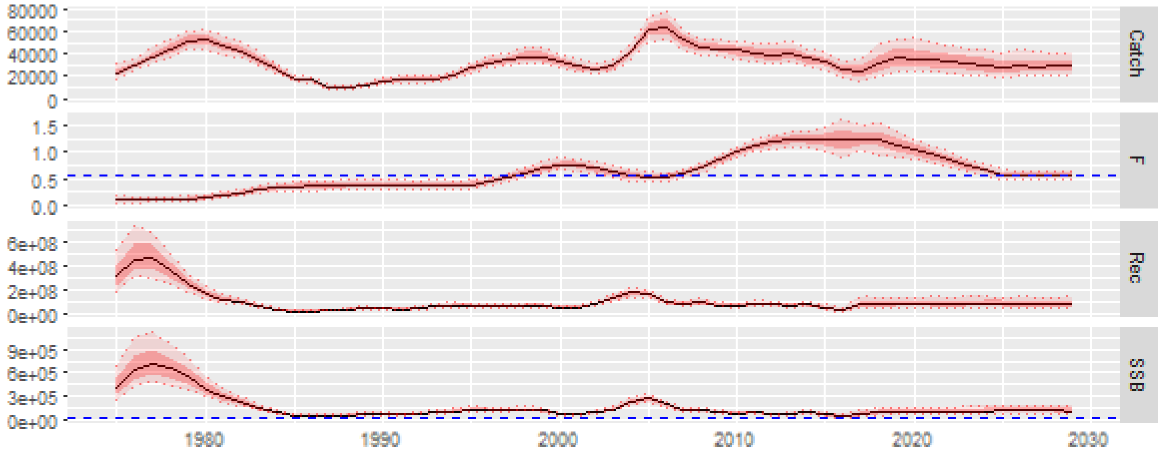

Figure 4.1.3.3. Anchovy (maturity at age0 = 0.5): MSE projection (Scenario 2, linear reduction of F towards F_{MSY} in the period 2020-2025) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (32177 t).

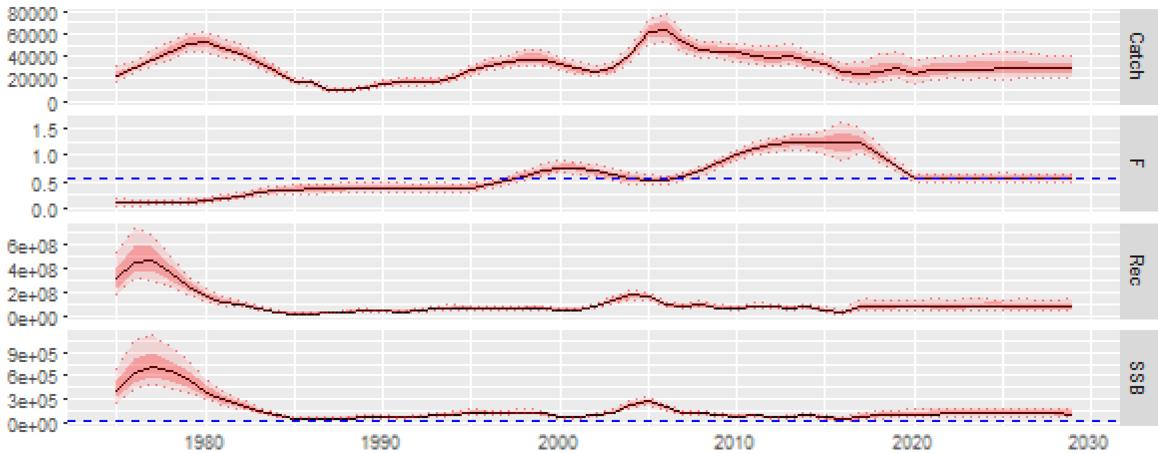

Figure 4.1.3.4. Anchovy (maturity at age0 = 0.5): MSE projection (Scenario 3, linear reduction of F towards F_{MSY} in the period 2019-2020) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (32177 t).

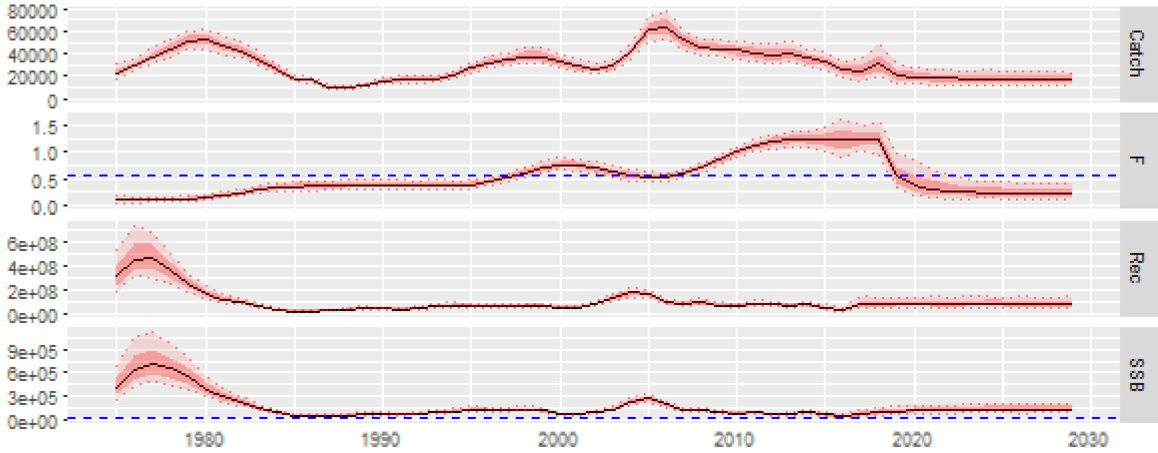

Figure 4.1.3.5. Anchovy (maturity at age0 = 0.5): MSE projection (Scenario 4, 10% catch reduction starting in 2019) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (32177 t).

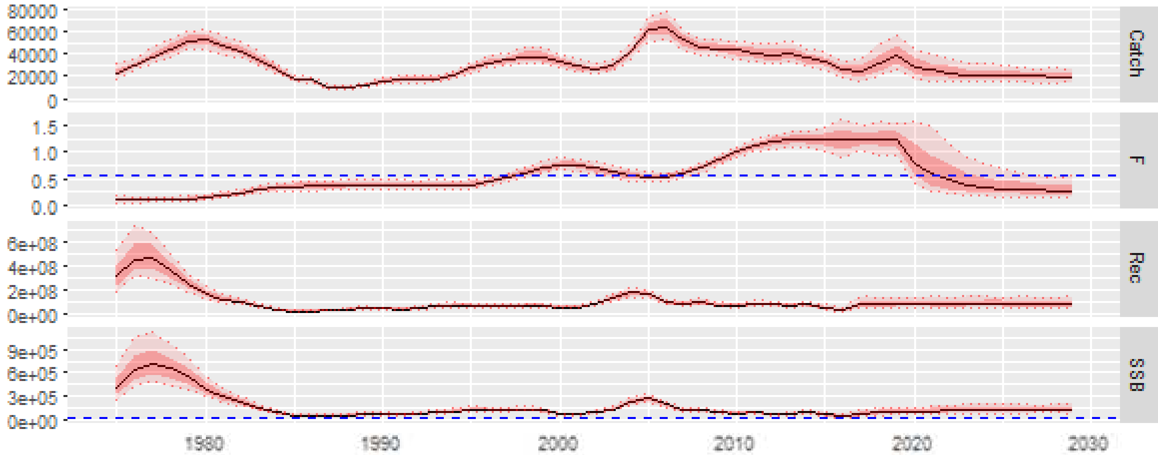

Figure 4.1.3.6. Anchovy (maturity at age0 = 0.5): MSE projection (Scenario 5, 10% catch reduction starting in 2020) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (32177 t).

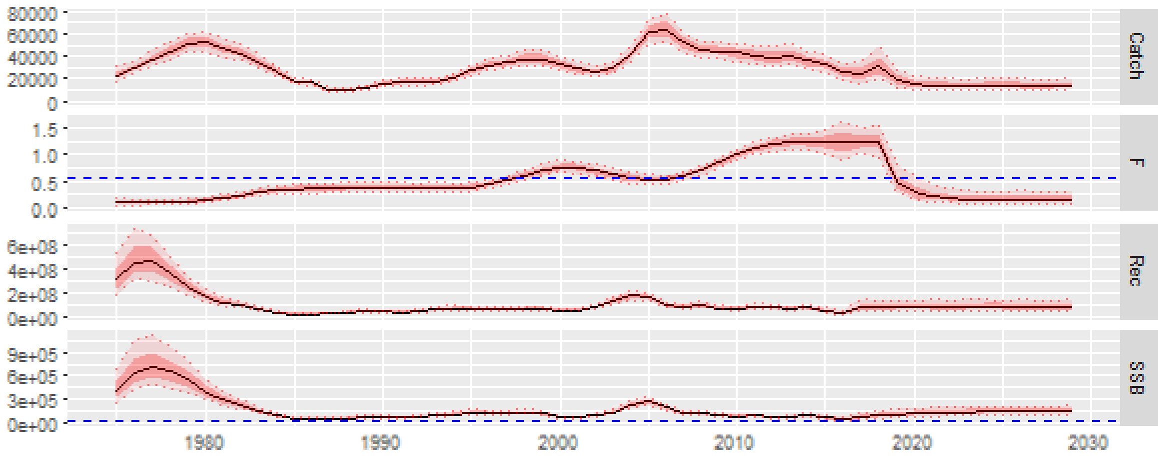

Figure 4.1.3.7. Anchovy (maturity at age0 = 0.5): MSE projection (Scenario 6, 20% catch reduction starting in 2019) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (32177 t).

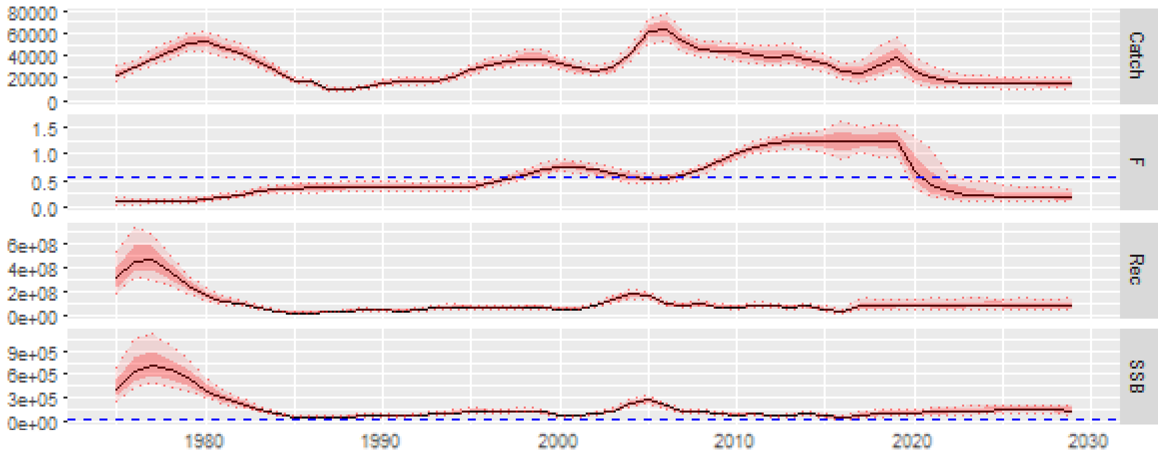

Figure 4.1.3.8. Anchovy (maturity at age0 = 0.5): MSE projection (Scenario 7, 20% catch reduction starting in 2020) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (32177 t).

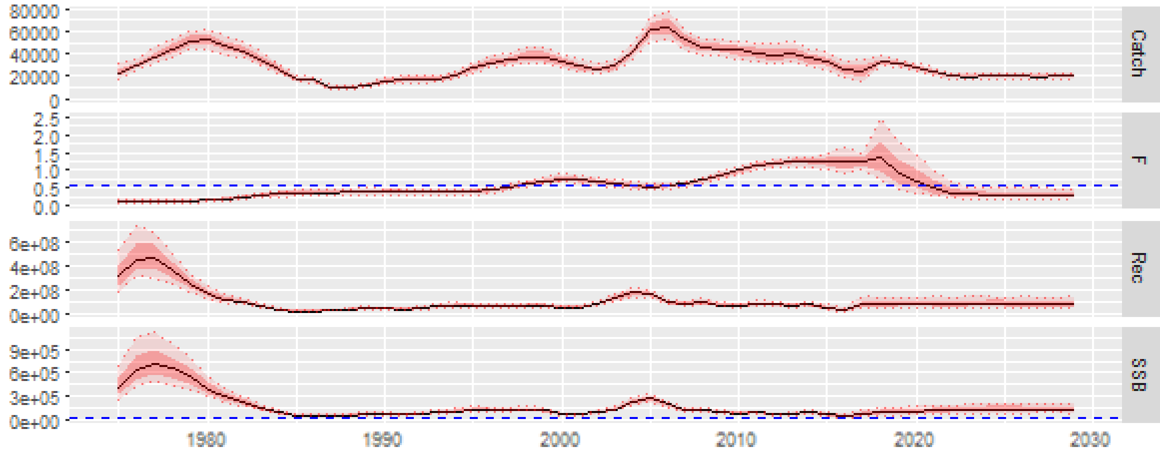

Figure 4.1.3.9. Anchovy (maturity at age0 = 0.5): MSE projection (Scenario 8, catch in 2018 equal to catch in 2014, then 5% reduction in 2018-2022) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (32177 t).

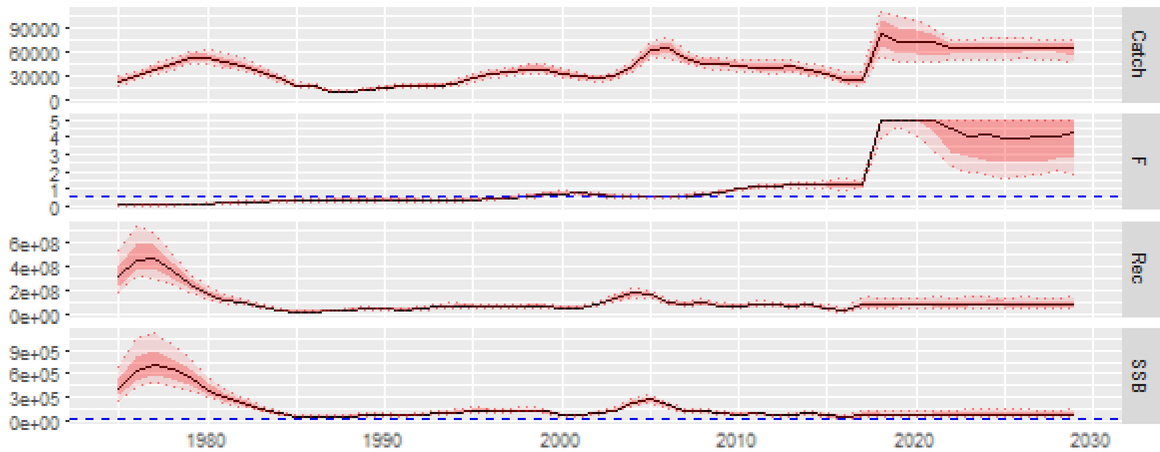

Figure 4.1.3.10. Anchovy (maturity at age0 = 0.5): MSE projection (Scenario 9, catch in 2018 equal to total catches in 2014, then 5% reduction in 2018-2022) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (32177 t).

Table 4.1.3.1. Anchovy (maturity at age0 = 0.5): probability of SSB falling below B_{lim} by year and Scenario. SQ: Status quo, mean F_{bar} of the last 3 years 2014-2016; S1: linear reduction of F towards F_{MSY} in the period 2019-2025; S2: linear reduction of F towards F_{MSY} in the period 2020-2025; S3: linear reduction of F towards F_{MSY} in the period 2019-2020; S4: 10% catch reduction 2019-2030; S5: 10% catch reduction 2020-2030; S6: 20% catch reduction 2019-2030; S7: 20% catch reduction 2020-2030; S8: catch in 2018 equal to catch in 2014, then 5% reduction 2018-2022; S9: catch in 2018 equal to total catches in 2014, then 5% reduction 2018-2022.

Year	SQ	S1	S2	S3	S4	S5	S6	S7	S8	S9
2016	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
2017	1.2	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
2018	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	2.0
2019	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
2020	0.0	0.0	0.0	0.0	0.4	0.4	0.4	0.4	0.0	2.0
2021	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.4	0.0	1.6
2022	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.4	2.4
2023	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	3.2
2024	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2
2025	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6
2026	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
2027	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8
2028	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4
2029	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0

4.1.4 Anchovy in GSAs 17-18 (maturity at age0 = 0.5; Constant M)

The results of the MSE projections for the anchovy stock with a maturity at age0 set to 0.5, and a scalar natural mortality (M) are shown in the Figures 4.1.4.1-4.1.4.10 and Table 4.1.4.1.

These scenarios should be seen as robustness tests of section 4.1.3. The comments presented are also relevant here. Overall, the mis-specification of natural mortality has a negative impact in the HCR performance, although generally still showing risk values within the 5% limit. These results would need further exploration to understand which effect is having this negative impact.

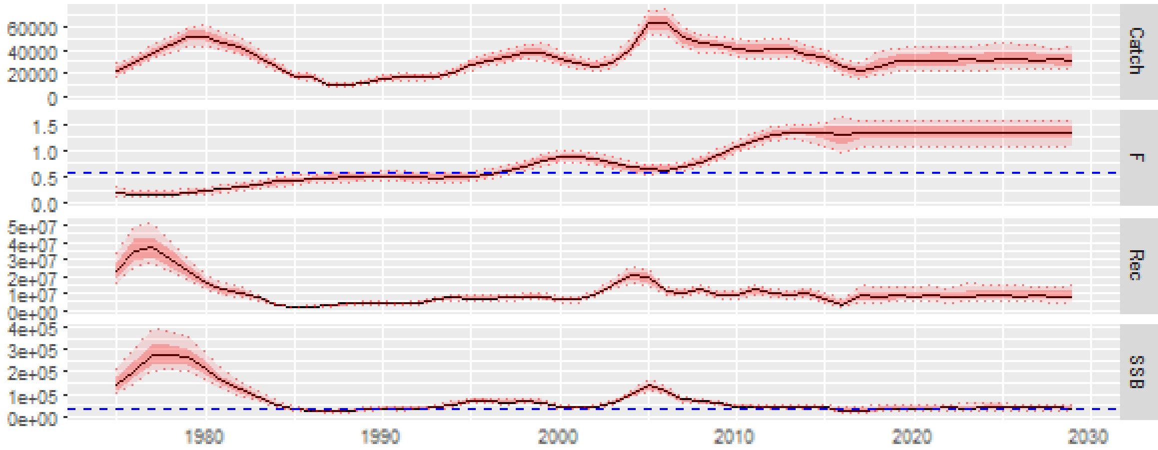

Figure 4.1.4.1. Anchovy (maturity at age0 = 0.5; constant M): MSE projection (Status quo, mean F_{bar} of the last 3 years, 2014-2016) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (32177 t).

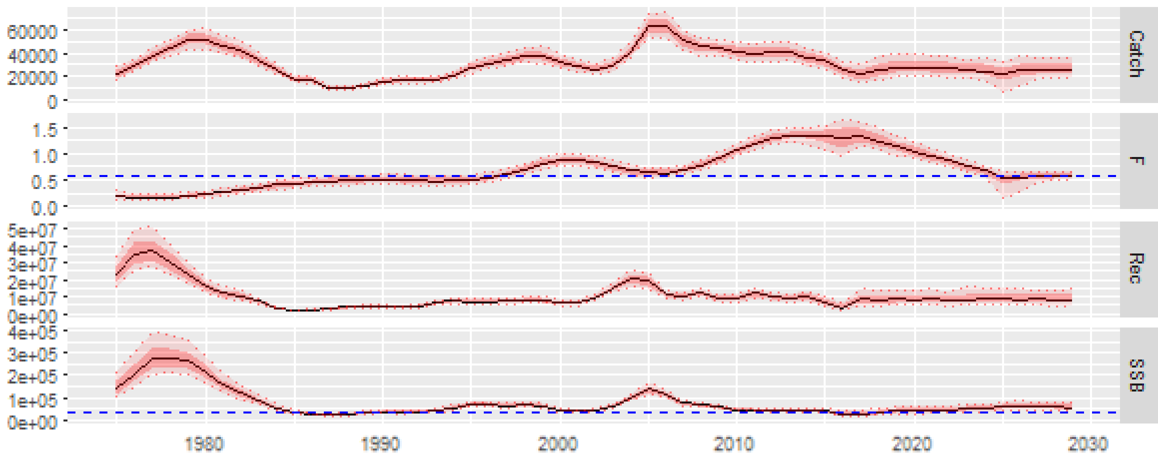

Figure 4.1.4.2. Anchovy (maturity at age0 = 0.5; constant M): MSE projection (Scenario 1, linear reduction of F towards F_{MSY} in the period 2019-2025) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (32177 t).

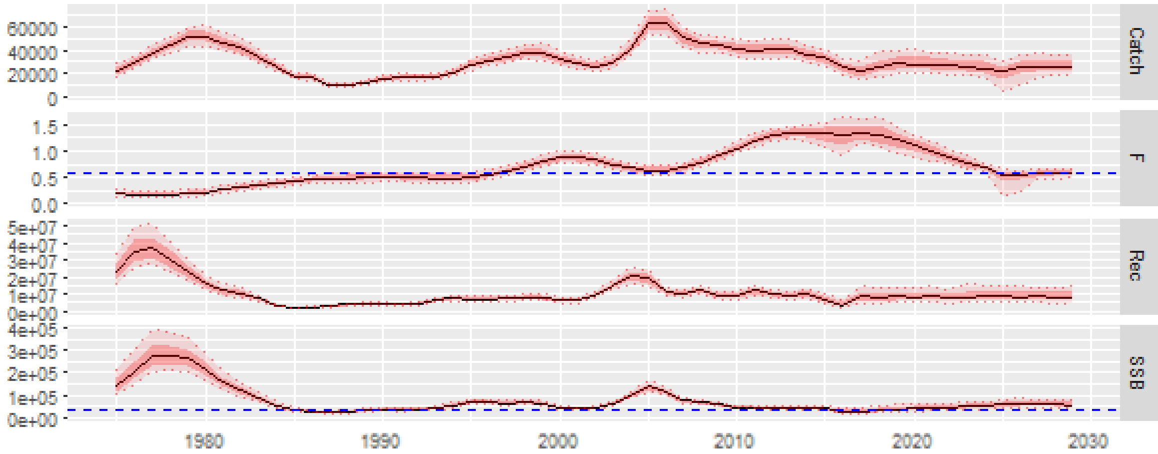

Figure 4.1.4.3. Anchovy (maturity at age0 = 0.5; constant M): MSE projection (Scenario 2, linear reduction of F towards F_{MSY} in the period 2020-2025) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (32177 t).

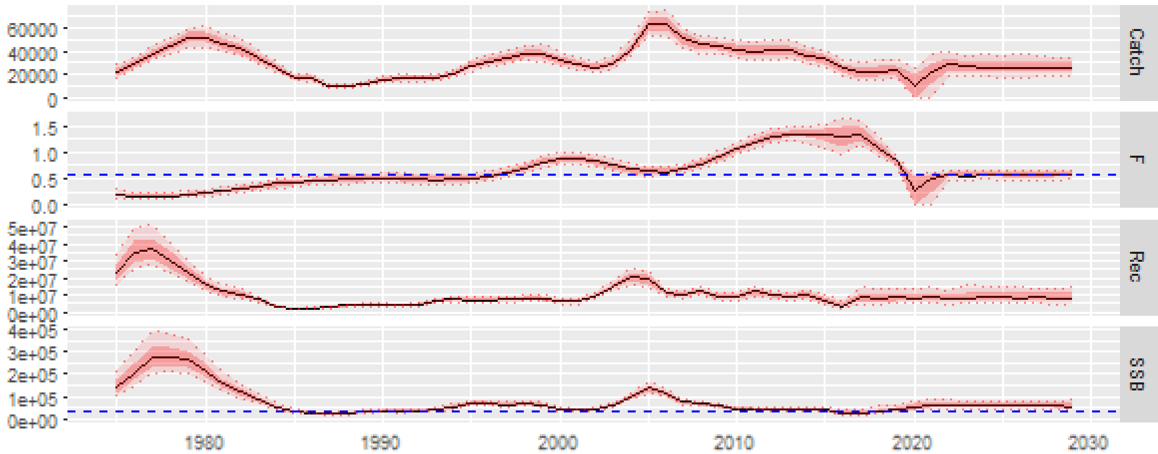

Figure 4.1.4.4. Anchovy (maturity at age0 = 0.5; constant M): MSE projection (Scenario 3, linear reduction of F towards F_{MSY} in the period 2019-2020) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (32177 t).

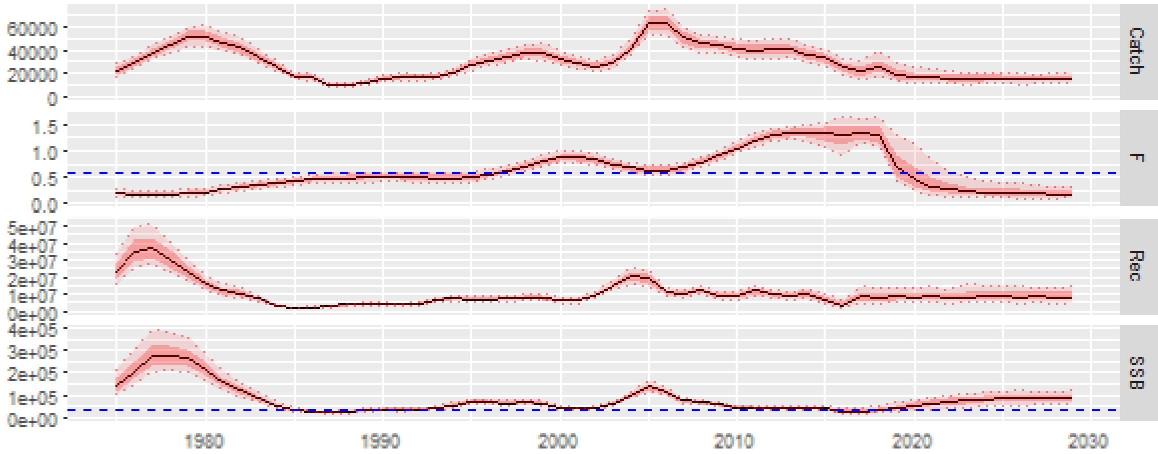

Figure 4.1.4.5. Anchovy (maturity at age0 = 0.5; constant M): MSE projection (Scenario 4, 10% catch reduction starting in 2019) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (32177 t).

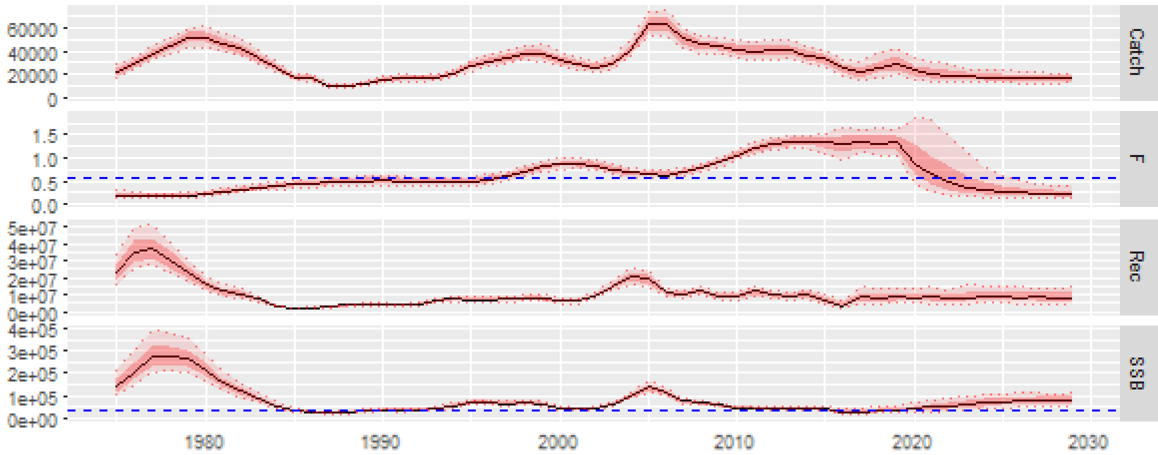

Figure 4.1.4.6. Anchovy (maturity at age0 = 0.5; constant M): MSE projection (Scenario 5, 10% catch reduction starting in 2020) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (32177 t).

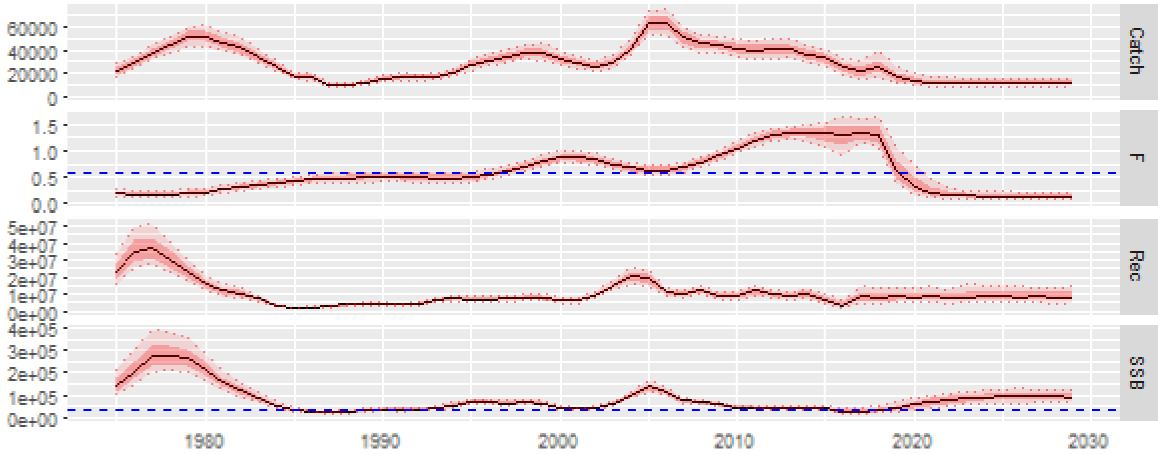

Figure 4.1.4.7. Anchovy (maturity at age0 = 0.5; constant M): MSE projection (Scenario 6, 20% catch reduction starting in 2019) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (32177 t).

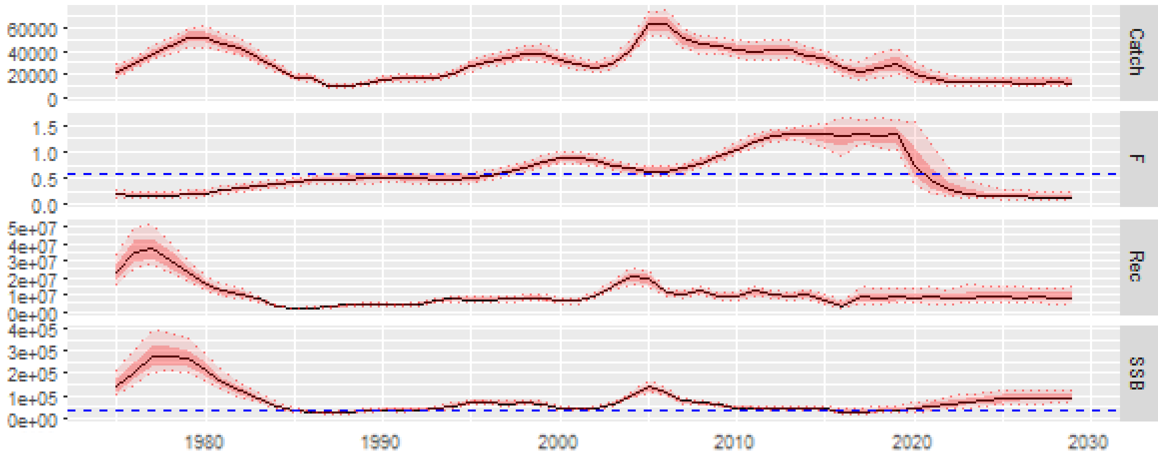

Figure 4.1.4.8. Anchovy (maturity at age0 = 0.5; constant M): MSE projection (Scenario 7, 20% catch reduction starting in 2020) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (32177 t).

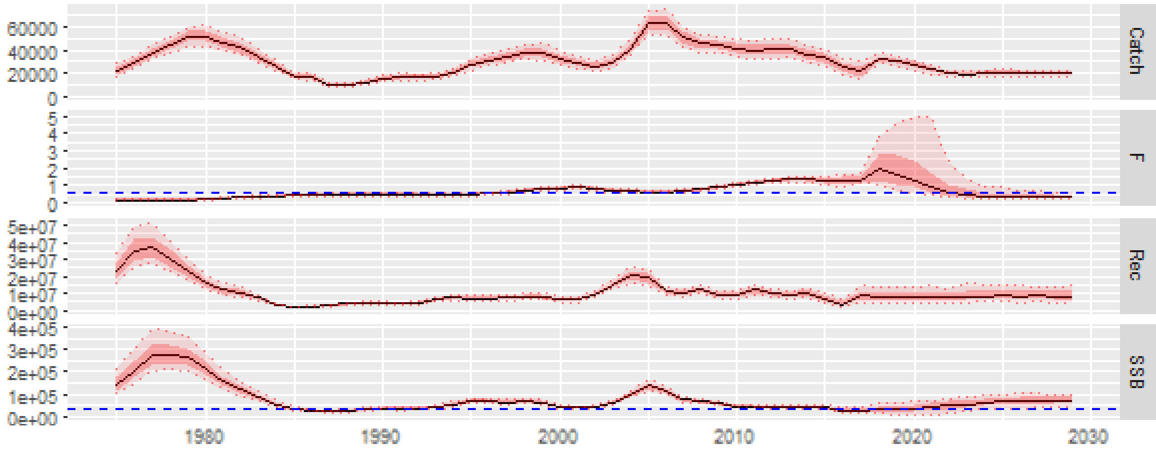

Figure 4.1.4.9. Anchovy (maturity at age0 = 0.5; constant M): MSE projection (Scenario 8, catch in 2018 equal to catch in 2014, then 5% reduction in 2018-2022) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (32177 t).

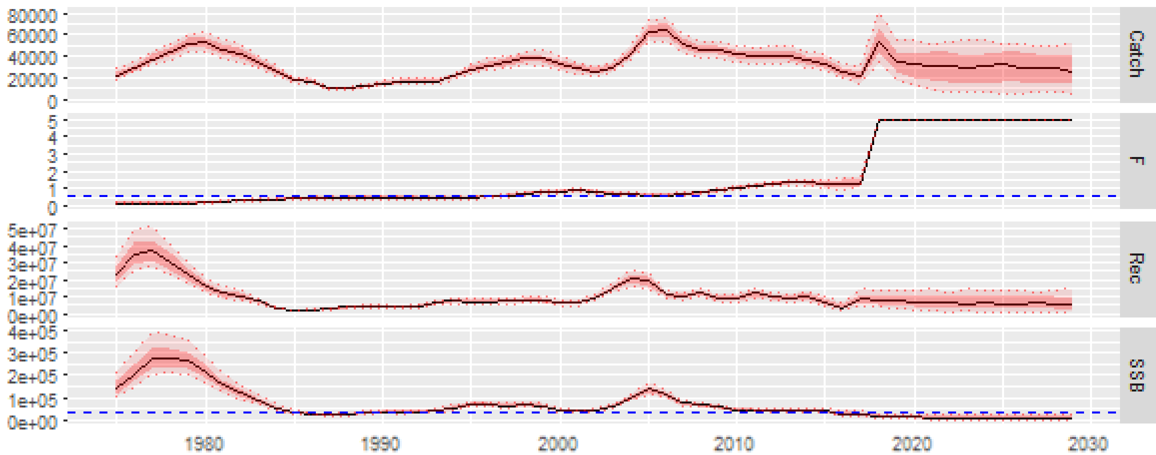

Figure 4.1.4.10. Anchovy (maturity at age0 = 0.5; constant M): MSE projection (Scenario 9, catch in 2018 equal to total catches in 2014, then 5% reduction in 2018-2022) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.57) and B_{lim} (32177 t).

Table 4.1.4.1. Anchovy (maturity at age0 = 0.5; constant M): probability of SSB falling below B_{lim} by year and Scenario. SQ: Status quo, mean F_{bar} of the last 3 years 2014-2016; S1: linear reduction of F towards F_{MSY} in the period 2019-2025; S2: linear reduction of F towards F_{MSY} in the period 2020-2025; S3: linear reduction of F towards F_{MSY} in the period 2019-2020; S4: 10% catch reduction 2019-2030; S5: 10% catch reduction 2020-2030; S6: 20% catch reduction 2019-2030; S7: 20% catch reduction 2020-2030; S8: catch in 2018 equal to catch in 2014, then 5% reduction 2018-2022; S9: catch in 2018 equal to total catches in 2014, then 5% reduction 2018-2022.

Year	SQ	S1	S2	S3	S4	S5	S6	S7	S8	S9
2016	76.4	76.4	76.4	76.4	76.4	76.4	76.4	76.4	76.4	76.4
2017	62.4	62.0	62.0	62.0	62.0	62.0	62.0	62.0	62.0	62.0
2018	33.2	30.0	30.4	24.8	30.4	30.4	30.4	30.4	52.0	94.8
2019	27.2	19.6	24.4	10.8	15.6	28.8	13.2	28.8	44.4	97.2
2020	23.2	14.4	17.2	1.2	9.6	22.4	4.4	18.8	38.8	98.0
2021	24.0	10.0	10.8	0.0	4.8	16.4	2.0	10.0	29.2	98.8
2022	27.2	7.6	9.2	0.4	3.2	9.6	0.4	4.0	22.0	98.0
2023	24.8	4.4	6.4	1.6	2.8	8.4	0.8	2.0	12.0	96.8
2024	21.6	2.8	4.0	1.2	2.0	6.0	0.8	1.6	9.6	95.6
2025	21.6	0.0	0.0	0.0	2.0	3.2	0.4	0.4	5.2	96.8
2026	21.6	0.8	0.8	0.8	0.8	3.6	0.0	0.0	5.2	96.8
2027	20.0	0.4	0.4	0.4	0.8	2.4	0.0	0.0	3.6	99.6
2028	21.2	0.0	0.0	0.0	0.8	1.2	0.0	0.0	2.0	98.4
2029	29.2	0.8	0.8	0.8	0.8	2.4	0.0	0.0	1.6	96.4

4.1.5 Sardine in GSAs 17-18

The results of the MSE projections for sardine are shown in the Figures 4.1.5.1-4.1.5.10 and Table 4.1.5.1.

The scenarios that are performing the best both in terms of probability of SSB falling below B_{lim} and ability of reaching F_{MSY} are Scenario 1, 2, and 3 (linear reduction of F towards F_{MSY} in 2019-2025, 2020-2025, and 2019-2020, respectively). Although scenarios based on catch reductions were not designed to reach F_{MSY}, in these scenarios, once F_{MSY} is reached, catches are kept constant for the rest of the forecast, since there were no indications of what management will look like after reaching the objective. Keeping catches at the level when F_{MSY} is reached for the first time, means that catches may be lower than MSY, if the stock is far from equilibrium, as such generating fishing mortalities lower than F_{MSY}.

Scenario 8 (catch in 2018 set to catch of sardine in 2014, then 5% reduction in the period 2018-2022) is providing the best results in terms of low probability of SSB falling below B_{lim}, and the ability of reaching F_{MSY}. Also the scenarios based on 10% catch reduction are able to bring F towards F_{MSY}, despite allowing SSB recovering above B_{lim} only in the last few years of the projections. Scenarios based on 20% catch reduction are performing better in terms of probability of SSB falling below B_{lim}; however, they bring F to fall below F_{MSY}.

Note that recruitment in the projections is higher than the most recent estimations. This is due to the use of a segmented regression model for recruitment, which assumes average recruitment over a wide range of SSB values. The EWG found a S/R linear model, which shows a decrease of recruitment at low levels of SSB. This effect was not captured by the model used in the projections, and as such the model projections may be optimistic and should be taken with care. This effect is very clear in the Status quo scenario, which seems to recover SSB and catches at high levels of F. This result must be considered as not reliable.

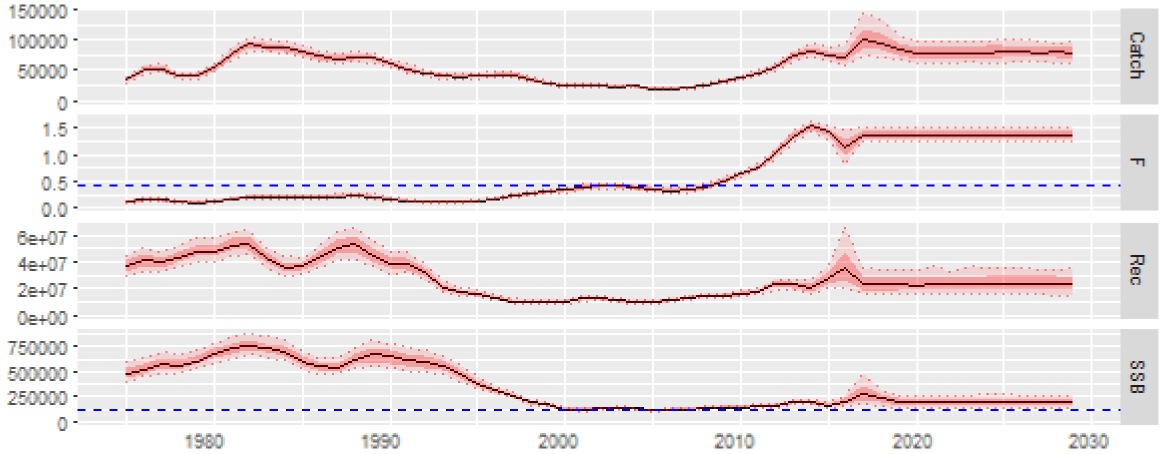

Figure 4.1.5.1. Sardine: MSE projection (Status quo, mean F_{bar} of the last 3 years, 2014-2016) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.44) and B_{lim} (112922 t).

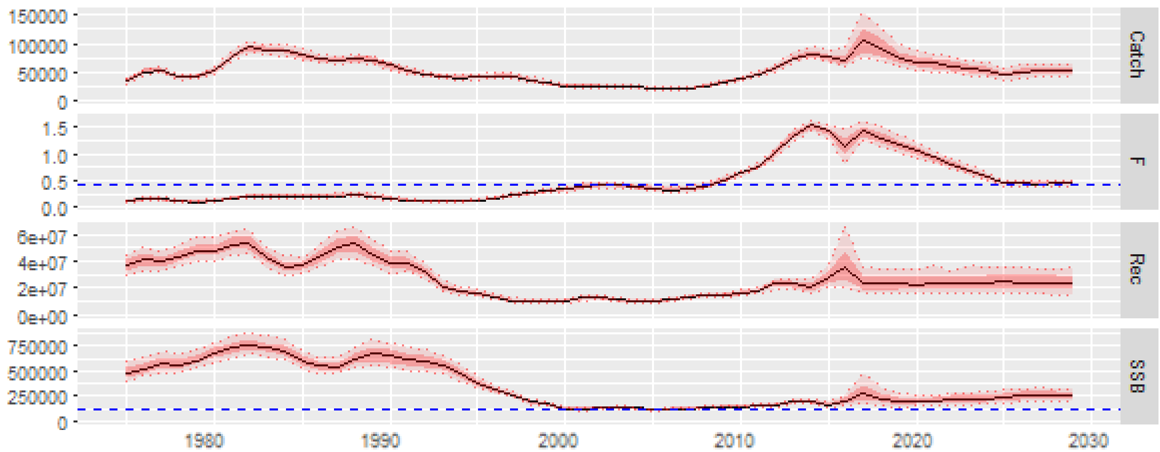

Figure 4.1.5.2. Sardine: MSE projection (Scenario 1, linear reduction of F towards F_{MSY} in the period 2019-2025) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.44) and B_{lim} (112922 t).

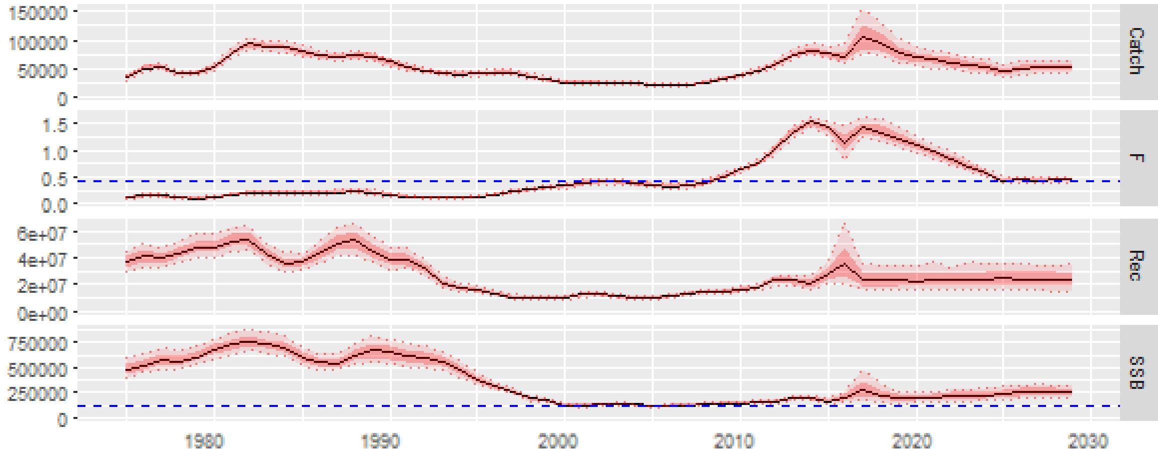

Figure 4.1.5.3. Sardine: MSE projection (Scenario 2, linear reduction of F towards F_{MSY} in the period 2020-2025) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.44) and B_{lim} (112922 t).

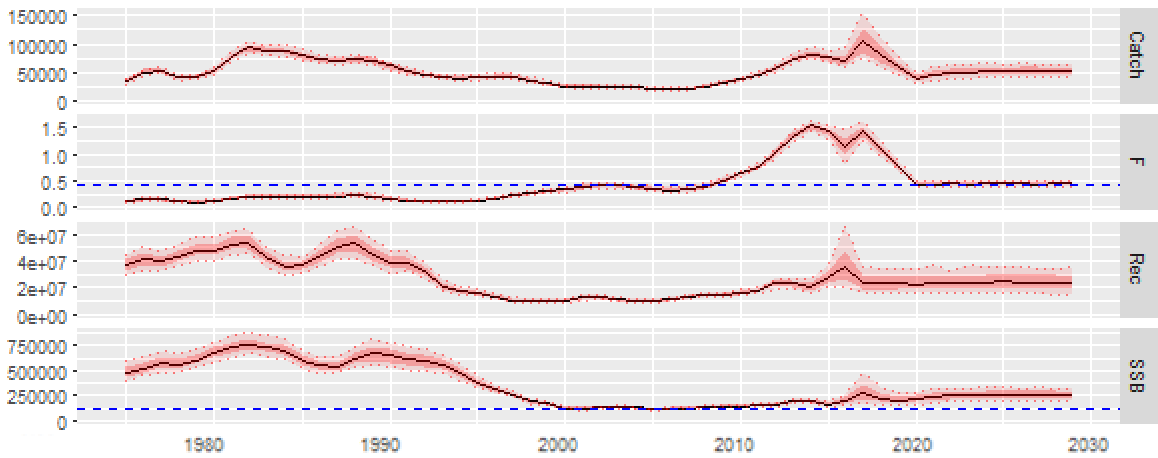

Figure 4.1.5.4. Sardine: MSE projection (Scenario 3, linear reduction of F towards F_{MSY} in the period 2019-2020) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.44) and B_{lim} (112922 t).

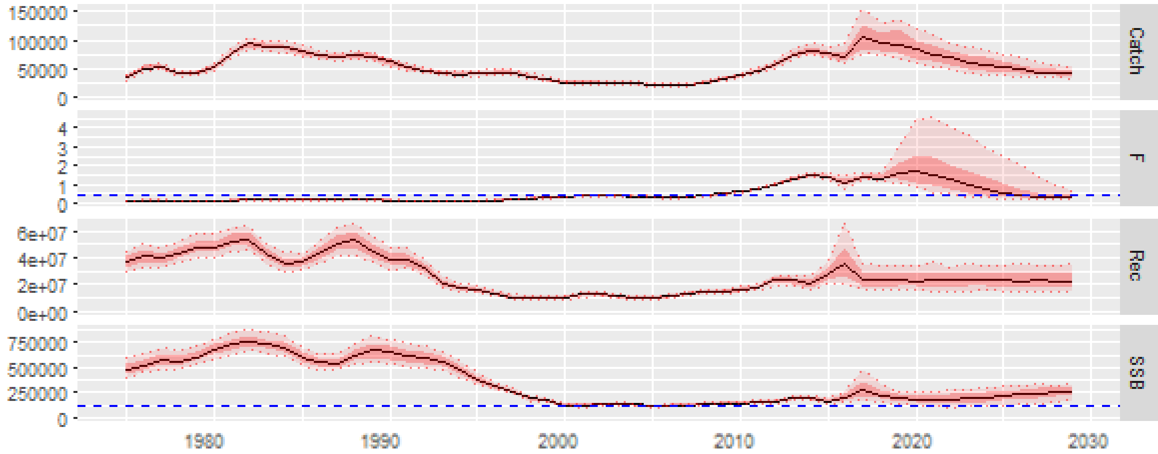

Figure 4.1.5.5. Sardine: MSE projection (Scenario 4, 10% catch reduction starting in 2019) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.44) and B_{lim} (112922 t).

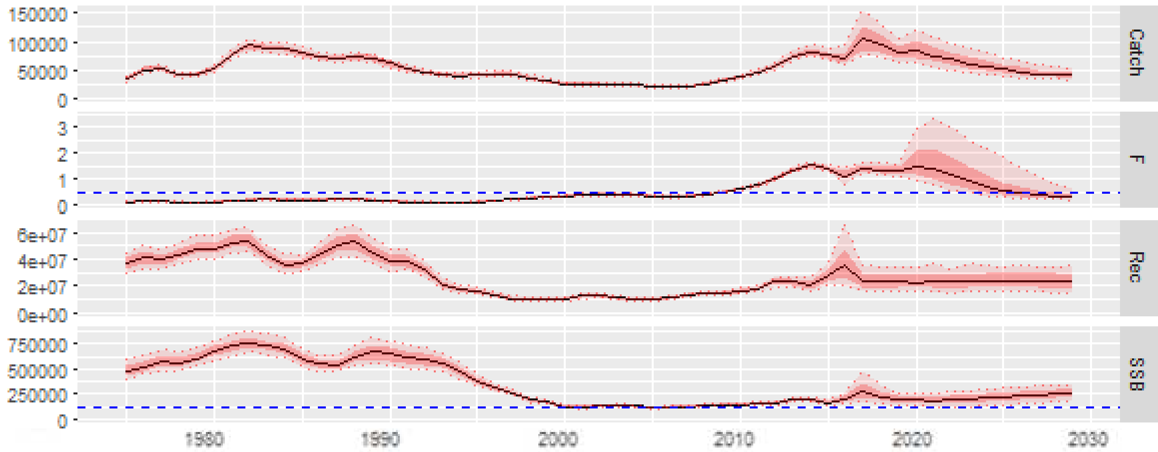

Figure 4.1.5.6. Sardine: MSE projection (Scenario 5, 10% catch reduction starting in 2020) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.44) and B_{lim} (112922 t).

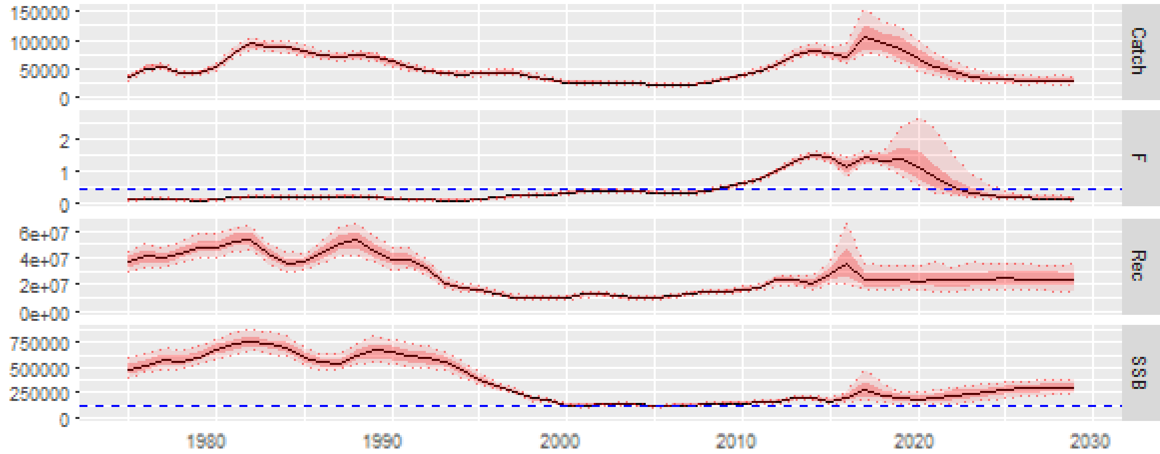

Figure 4.1.5.7. Sardine: MSE projection (Scenario 6, 20% catch reduction starting in 2019) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.44) and B_{lim} (112922 t).

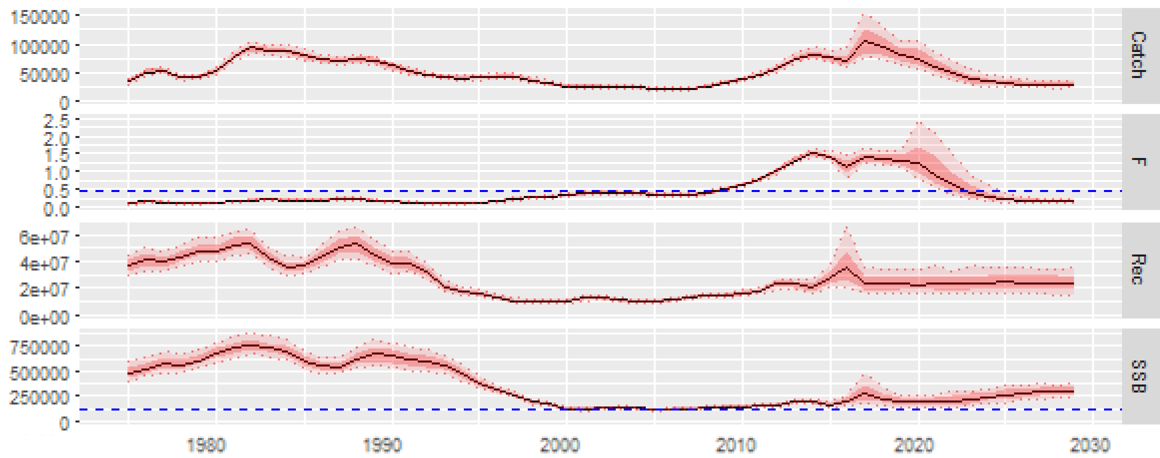

Figure 4.1.5.8. Sardine: MSE projection (Scenario 7, 20% catch reduction starting in 2020) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.44) and B_{lim} (112922 t).

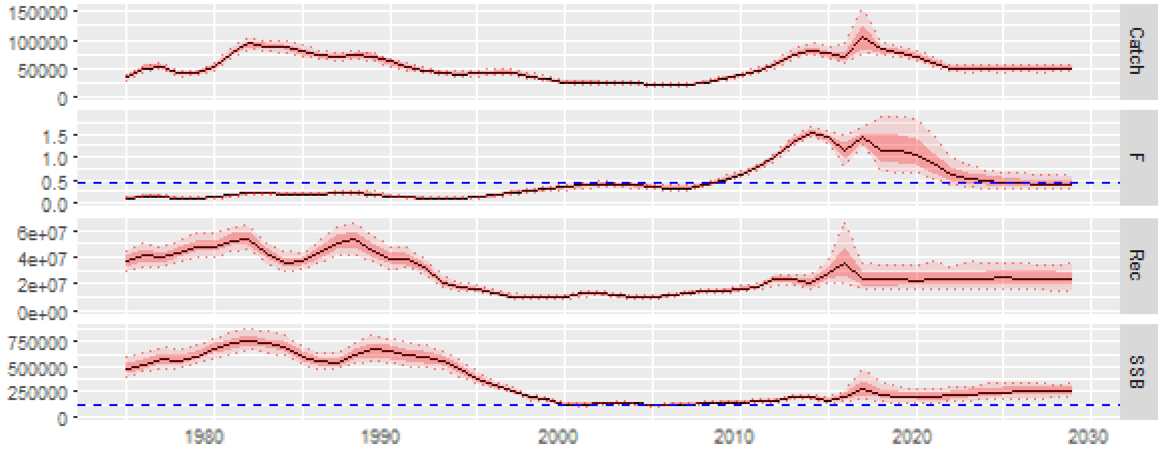

Figure 4.1.5.9. Sardine: MSE projection (Scenario 8, catch in 2018 equal to catch in 2014, then 5% reduction in 2018-2022) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.44) and B_{lim} (112922 t).

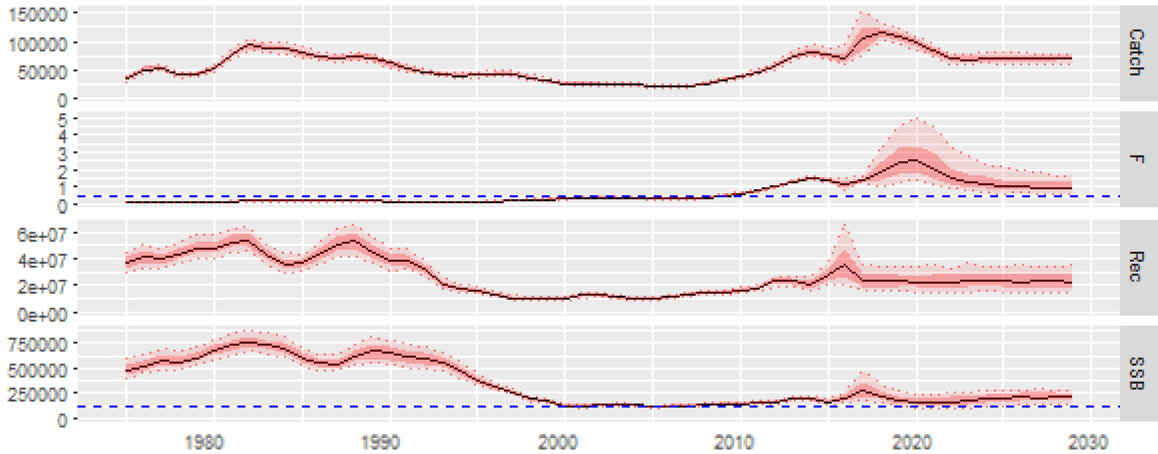

Figure 4.1.5.10. Sardine: MSE projection (Scenario 9, catch in 2018 equal to total catches in 2014, then 5% reduction in 2018-2022) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.44) and B_{lim} (112922 t).

Table 4.1.5.1. Sardine: probability of SSB falling below B_{lim} by year and Scenario. SQ: Status quo, mean F_{bar} of the last 3 years 2014-2016; S1: linear reduction of F towards F_{MSY} in the period 2019-2025; S2: linear reduction of F towards F_{MSY} in the period 2020-2025; S3: linear reduction of F towards F_{MSY} in the period 2019-2020; S4: 10% catch reduction 2019-2030; S5: 10% catch reduction 2020-2030; S6: 20% catch reduction 2019-2030; S7: 20% catch reduction 2020-2030; S8: catch in 2018 equal to catch in 2014, then 5% reduction 2018-2022; S9: catch in 2018 equal to total catches in 2014, then 5% reduction 2018-2022.

Year	SQ	S1	S2	S3	S4	S5	S6	S7	S8	S9
2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2017	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2018	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2019	1.2	0.8	1.6	0.4	1.6	1.6	1.6	1.6	2.8	7.2
2020	0.0	0.0	0.0	0.0	6.4	0.0	4.0	0.0	3.2	14.0
2021	0.8	0.4	0.4	0.0	7.6	4.4	4.4	3.2	4.0	19.6
2022	1.2	0.0	0.0	0.0	11.2	8.0	5.2	3.6	0.0	18.4
2023	1.2	0.4	0.4	0.0	10.0	6.0	2.8	2.4	0.4	12.4
2024	2.0	0.0	0.0	0.0	10.4	7.2	1.2	1.2	0.8	8.4
2025	0.4	0.0	0.0	0.0	8.4	6.0	0.4	0.4	0.4	8.0
2026	0.4	0.0	0.0	0.0	6.8	2.4	0.4	0.4	0.4	5.6
2027	1.2	0.0	0.0	0.0	4.0	3.6	0.0	0.4	0.4	5.6
2028	0.4	0.0	0.0	0.0	4.8	2.8	0.0	0.0	0.4	4.0
2029	0.4	0.0	0.0	0.0	3.2	1.6	0.0	0.0	0.0	4.0

4.1.6 Sardine in GSAs 17-18 (Constant M)

The results of the MSE projections for the sardine stock with a scalar natural mortality (M = 0.55) are shown in the Figures 4.1.6.1-4.1.6.10 and Table 4.1.6.1.

These scenarios should be seen as robustness tests of section 4.1.5. The comments presented are also relevant here. Overall, the mis-specification of natural mortality has a negative impact in the HCR performance of catch options scenarios. These results would need further exploration to understand which effect is having this negative impact.

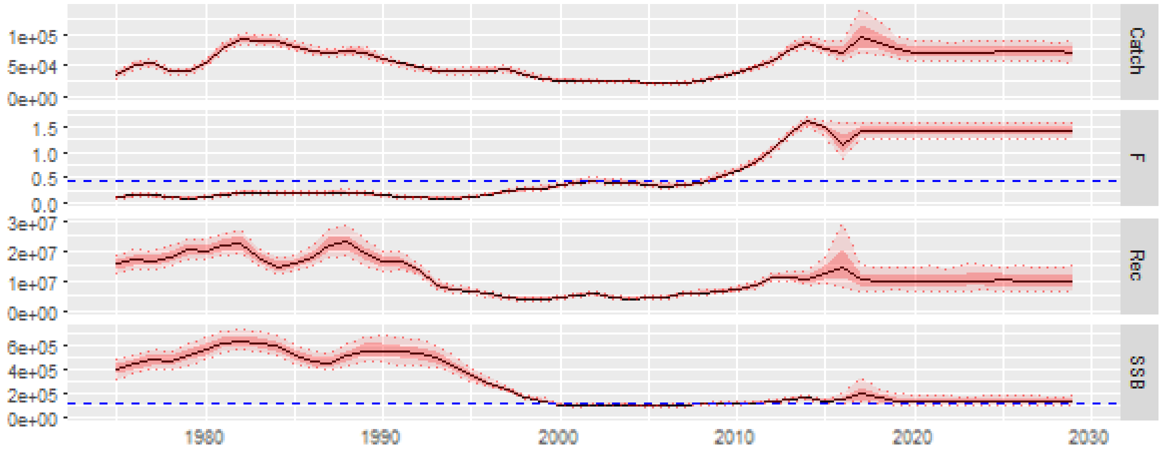

Figure 4.1.6.1. Sardine (constant M): MSE projection (Status quo, mean F_{bar} of the last 3 years, 2014-2016) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.44) and B_{lim} (112922 t).

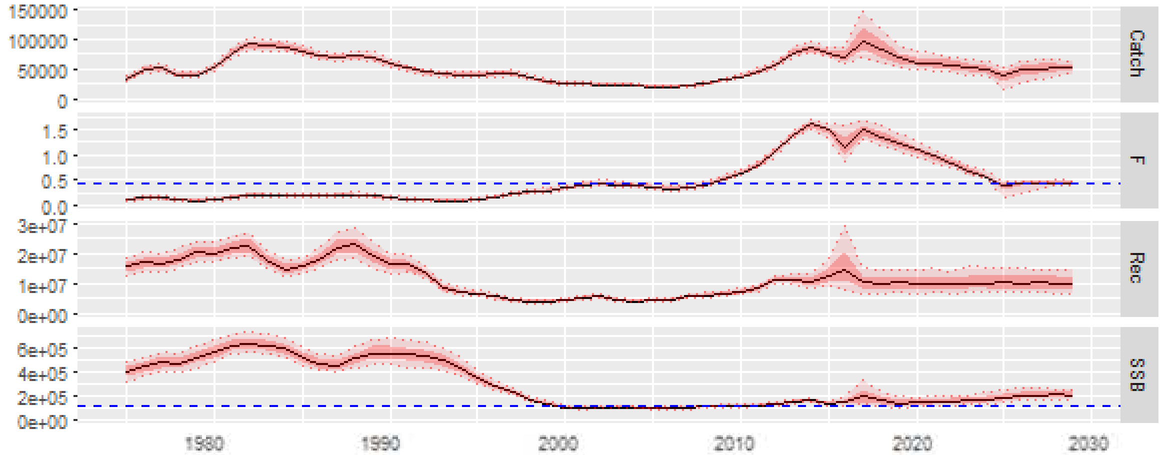

Figure 4.1.6.2. Sardine (constant M): MSE projection (Scenario 1, linear reduction of F towards F_{MSY} in the period 2019-2025) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.44) and B_{lim} (112922 t).

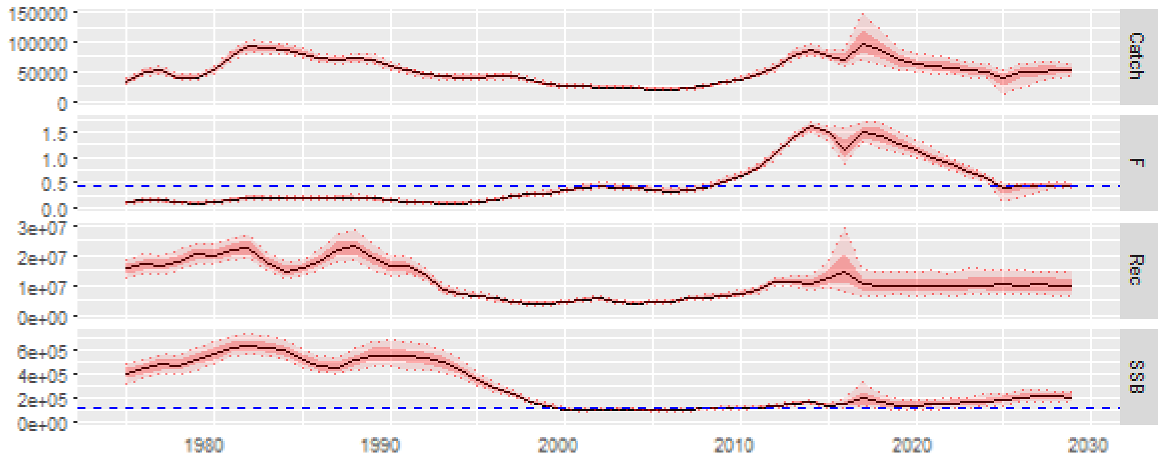

Figure 4.1.6.3. Sardine (constant M): MSE projection (Scenario 2, linear reduction of F towards F_{MSY} in the period 2020-2025) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.44) and B_{lim} (112922 t).

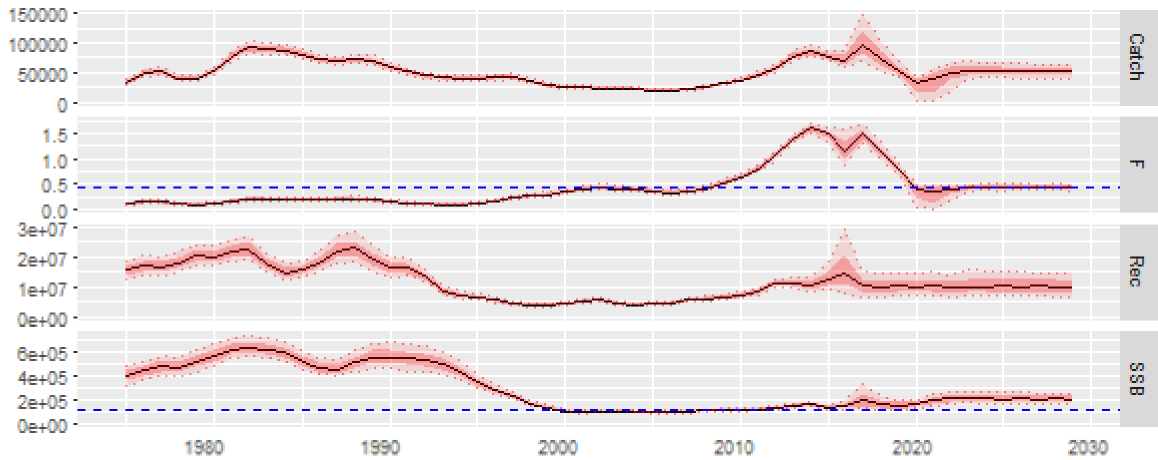

Figure 4.1.6.4. Sardine (constant M): MSE projection (Scenario 3, linear reduction of F towards F_{MSY} in the period 2019-2020) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.44) and B_{lim} (112922 t).

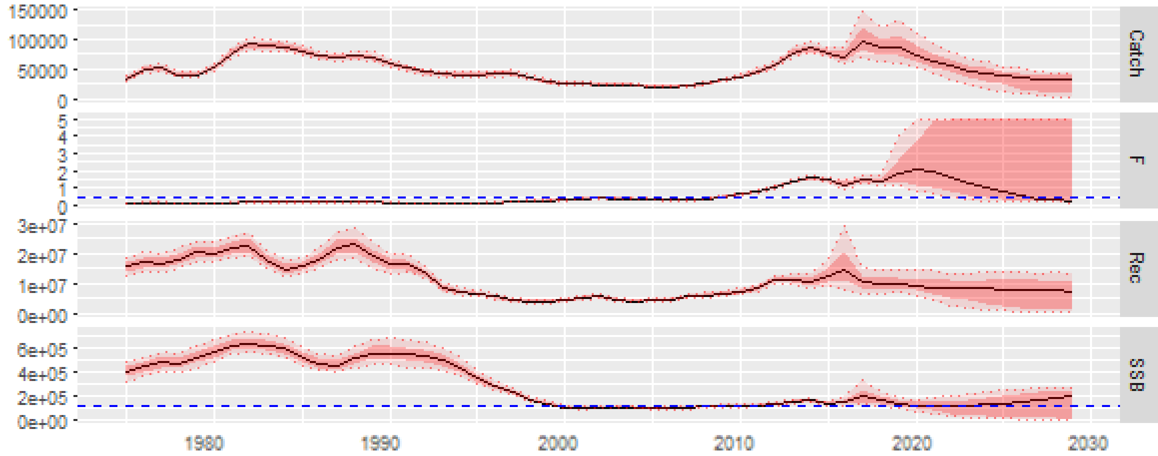

Figure 4.1.6.5. Sardine (constant M): MSE projection (Scenario 4, 10% catch reduction starting in 2019) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.44) and B_{lim} (112922 t).

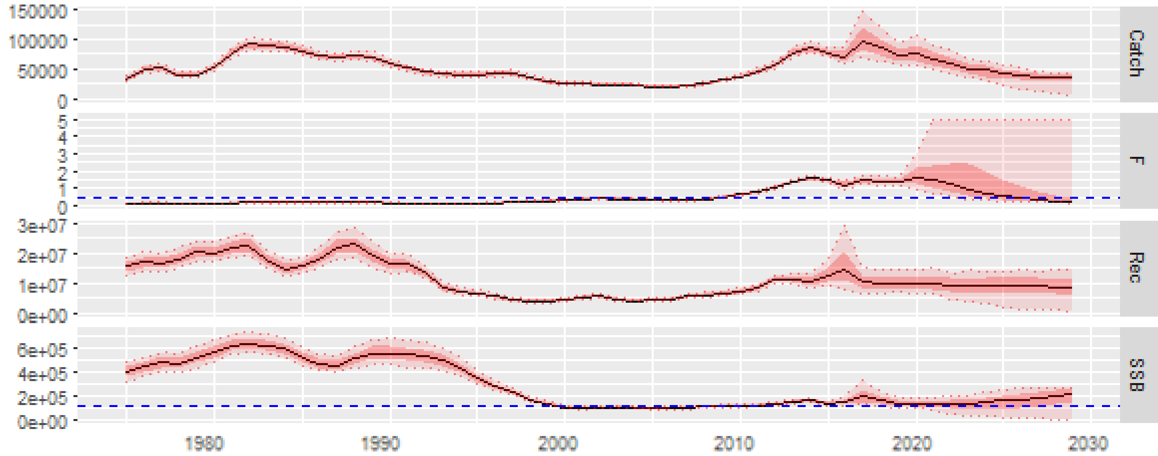

Figure 4.1.6.6. Sardine (constant M): MSE projection (Scenario 5, 10% catch reduction starting in 2020) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.44) and B_{lim} (112922 t).

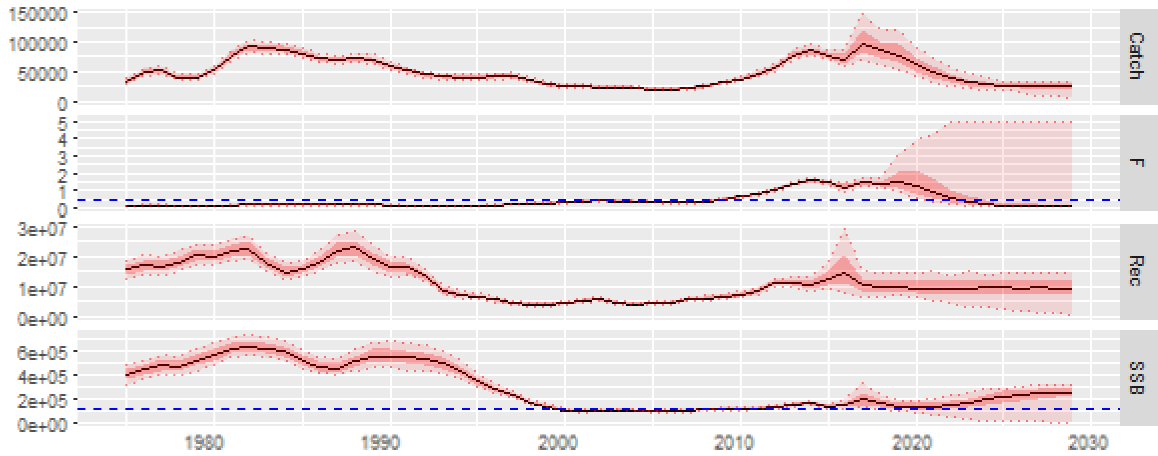

Figure 4.1.6.7. Sardine (constant M): MSE projection (Scenario 6, 20% catch reduction starting in 2019) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.44) and B_{lim} (112922 t).

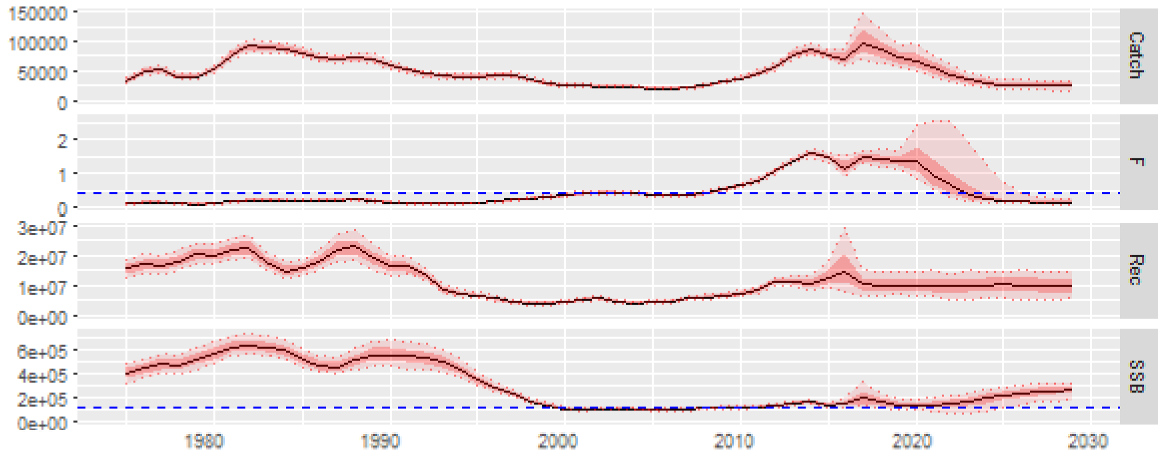

Figure 4.1.6.8. Sardine (constant M): MSE projection (Scenario 7, 20% catch reduction starting in 2020) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.44) and B_{lim} (112922 t).

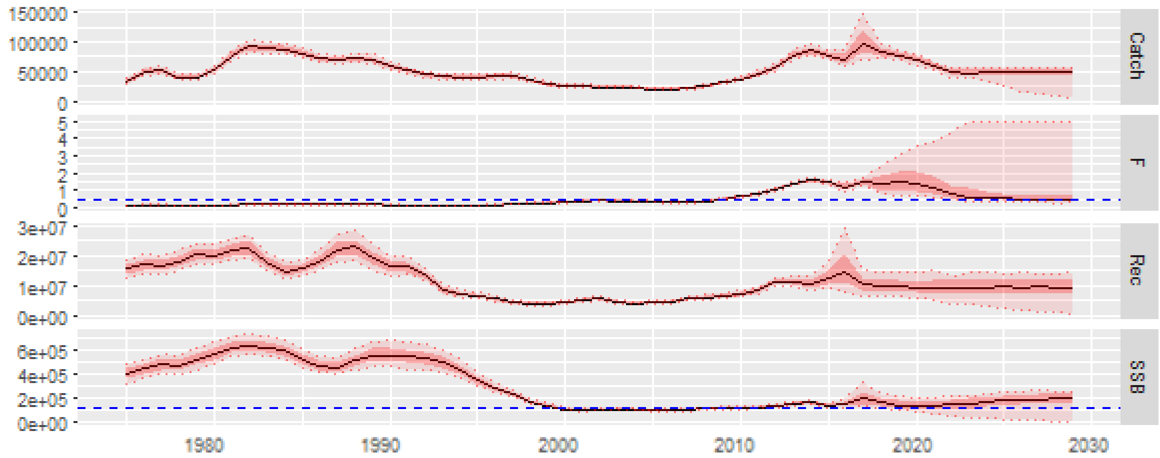

Figure 4.1.6.9. Sardine (constant M): MSE projection (Scenario 8, catch in 2018 equal to catch in 2014, then 5% reduction in 2018-2022) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.44) and B_{lim} (112922 t).

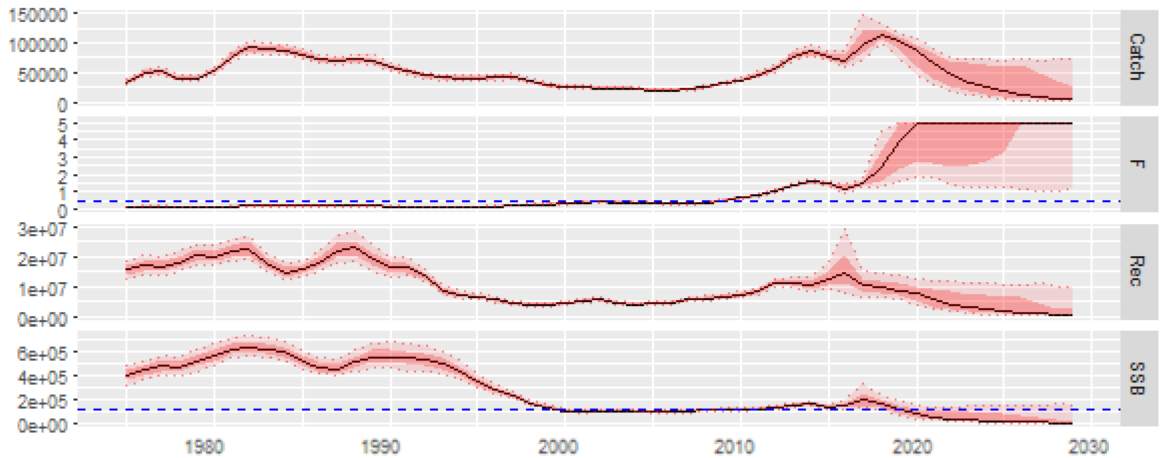

Figure 4.1.6.10. Sardine (constant M): MSE projection (Scenario 9, catch in 2018 equal to total catches in 2014, then 5% reduction in 2018-2022) based on the a4a model used to emulate the official assessment (SAM). Dashed blue line represents F_{MSY} (0.44) and B_{lim} (112922 t).

Table 4.1.6.1. Sardine (constant M): probability of SSB falling below B_{lim} by year and Scenario. SQ: Status quo, mean F_{bar} of the last 3 years 2014-2016; S1: linear reduction of F towards F_{MSY} in the period 2019-2025; S2: linear reduction of F towards F_{MSY} in the period 2020-2025; S3: linear reduction of F towards F_{MSY} in the period 2019-2020; S4: 10% catch reduction 2019-2030; S5: 10% catch reduction 2020-2030; S6: 20% catch reduction 2019-2030; S7: 20% catch reduction 2020-2030; S8: catch in 2018 equal to catch in 2014, then 5% reduction 2018-2022; S9: catch in 2018 equal to total catches in 2014, then 5% reduction 2018-2022.

Year	SQ	S1	S2	S3	S4	S5	S6	S7	S8	S9
2016	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8
2017	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6
2018	7.6	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4
2019	15.6	15.6	19.6	9.2	19.6	19.6	19.6	19.6	26.8	49.6
2020	16.4	11.6	14.0	3.6	39.6	15.6	29.6	15.6	30.0	69.2
2021	19.6	9.6	10.8	0.4	48.8	34.8	29.2	24.8	34.4	78.0
2022	22.4	4.8	6.8	0.0	50.8	34.4	25.6	23.2	30.8	82.8
2023	22.4	2.0	2.4	0.0	48.8	34.4	21.6	18.0	25.6	81.2
2024	19.2	2.0	2.0	0.0	44.0	32.4	17.6	13.2	19.6	80.8
2025	20.8	1.2	1.2	0.0	43.6	28.4	15.2	10.0	18.8	80.0
2026	16.8	0.0	0.0	0.0	39.6	26.4	14.4	9.6	17.2	82.4
2027	18.4	0.0	0.0	0.0	37.6	24.0	13.6	9.2	17.2	81.2
2028	17.6	0.0	0.0	0.0	36.0	22.4	13.6	9.2	16.4	82.4
2029	21.2	0.0	0.0	0.0	35.6	20.4	13.6	9.2	15.6	83.6

4.2 MSE projections with stock assessment uncertainty

The MSE projections in this study do not include stock assessment feedback, which should account for a fair amount of uncertainty. Such uncertainty and its impact in risk and performance of the HCR could not be accounted in the current analysis due to time constraints.

5. *Final comments*

MSE projections used in this study do not include stock assessment feedback, which should account for a fair amount of uncertainty. Such uncertainty and its impact in risk and performance of the HCR could not be accounted in the current analysis.

Scenarios based on linear reduction of fishing mortality are relying on the assumption that fishing mortality reduction will be proportional to the reduction in fishing effort. This is a rather strong assumption for small pelagic stocks (e.g. hyperstability; see Sadovy de Mitcheson et al., 2008).

Scenarios based on catch reductions were not designed to reach F_{MSY}. In these scenarios, once F_{MSY} is reached, catches are kept constant for the rest of the forecast, since there were no indications of what management will look like after reaching the objective. Keeping catches at the level when F_{MSY} is reached for the first time may provide catches lower than MSY, if the stock is far from equilibrium, as such generating fishing mortalities lower than F_{MSY}. These scenarios should be further explored to decide about which management will be implemented after reaching F_{MSY}.

In the view of these reasons, a straight comparison between the scenarios based on fishing mortality reduction and those based on catch reduction must be considered with caution.

Furthermore, it is worth recalling that recruitment in the projections is higher than the most recent estimations. This is due to the use of a segmented regression model for recruitment, which assumes average recruitment over a wide range of SSB values. The EWG found a S/R linear model, which shows a decrease of recruitment at low levels of SSB. This effect was not captured by the model used in the projections, and as such the model projections may be optimistic and should be taken with care. This effect is very clear in Status quo scenarios, which seem to recover SSB and catches at high levels of F.

For each of the three Operating Models (OM1: anchovy; OM3: anchovy with maturity at age0 set to 0.5; OM5: sardine) and three robustness test on natural mortality M (OM2: anchovy with constant M; OM4: anchovy with maturity at age0 set to 0.5 and constant M; OM6: sardine with constant M), Table 5.1 shows the number of years within the projected period that are characterized by a probability of SSB falling below B_{lim} lower than 5%. For anchovy with maturity at age0 set to be equal to 0.5 and sardine most of the scenarios shows a probability of SSB falling below B_{lim} lower than 5% in nearly all of the 14 projected years. Moreover, for anchovy with maturity at age0 set to be equal to 0, the Status quo scenario shows a probability of SSB falling below B_{lim} lower than 5% in all the 14 projected years.

In general, robustness tests show a deterioration of the HCRs performance. The mis-specification of natural mortality seems to have a negative impact. These results would need further exploration to understand which effect is creating the negative impact.

Table 5.1. Number of years (within the projected period, 14 years) with probability of SSB falling below B_{lim} less than 5%, by Operating Model (OM) and scenario. OM1: Anchovy; OM2: Anchovy with constant M; OM3: Anchovy with maturity at age0 = 0.5; OM4: Anchovy with maturity at age0 = 0.5 and constant M; OM5: Sardine; OM6; Sardine with constant M. OM2, OM4, and OM6 are considered as tests to check the effect of M. SQ: Status quo, mean F_{bar} of the last 3 years 2014-2016; S1: linear reduction of F towards F_{MSY} in the period 2019-2025; S2: linear reduction of F towards F_{MSY} in the period 2020-2025; S3: linear reduction of F towards F_{MSY} in the period 2019-2020; S4: 10% catch reduction starting in 2019; S5: 10% catch reduction starting in 2020; S6: 20% catch reduction starting in 2019; S7: 20% catch reduction starting in 2020; S8: catch in 2018 equal to catch in 2014, then 5% reduction 2018-2022; S9: catch in 2018 equal to total catches in 2014, then 5% reduction 2018-2022.

				Robustness tests		
Scenarios	**OM1**	**OM3**	**OM5**	**OM2**	**OM4**	**OM6**
SQ	0	13	14	0	0	0
S1	8	13	14	5	7	8
S2	8	13	14	5	6	7
S3	10	13	14	9	10	10
S4	7	13	7	0	9	0
S5	7	13	10	0	5	0
S6	8	13	13	0	10	6
S7	8	13	14	5	8	0
S8	0	13	14	0	3	0
S9	0	13	5	0	0	0

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ANNEX II

(from page 1 to page 8)

Assessment for All initiative(a4a)
The `a4a` Management Strategies Evaluation algorithm

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Abstract

This document presents the Management Strategies Evaluation algorithm developed in the JRC Assessment For All (`a4a`) Initiative. Management Strategy Evaluation (`MSE`) is a complex simulation and forecasting procedure that takes into account structural and observational uncertainty on stock dynamics (growth, recruitment, maturity) and on its exploitation by fishing fleets (selectivity, effort). The `MSE` paradigm can lead to to the articulation of the central part of a decision making framework for fisheries management under uncertainty. The `a4a` approach to `MSE` is to develop a set of common methods and procedures to build a minimal standard `MSE` algorithm, which has the most common elements of both uncertainty and management options. Such a toolset should allow for the development of `MSE` simulations for many fisheries in an operational time frame. The `a4a` `MSE` design uses a two step approach. The first step defines the 'standard' components of an `MSE` while the second step sets the details, for example the `HCR` or the `OM` conditioning.

Contents

1 Introduction

Management Strategy Evaluation (`MSE`) is a complex simulation and forecasting procedure that takes into account structural and observational uncertainty on stock dynamics (growth, recruitment, maturity) and on its exploitation by fishing fleets (selectivity, effort). The `MSE` paradigm can lead to to the articulation of the central part of a decision making framework for fisheries management under uncertainty. The algorithms for development and application of MSE simulations are currently fairly diverse across different fora and fisheries, despite the obvious common elements and a shared overall structure.

Figure 1 shows the major components in the fisheries system, how they relate and interact, and their position in the the fisheries management cycle. The industry, in most cases comprising private companies, manage fleets of fishing vessels exploiting the public marine resources. Scientific institutions then collect data on both the activity of the industry and the biological resources, in order to build a model representing both fleets and stocks dynamics. These models form the basis for scientific advice to the corresponding management body on how distinct policy options will affect the whole system, fleets and stocks. This management body (government, international institution or RFMO) has the institutional responsibility of managing these public marine resources for the common good. This requires the setting of appropriate regulations to steer and limit the activity of fishing.

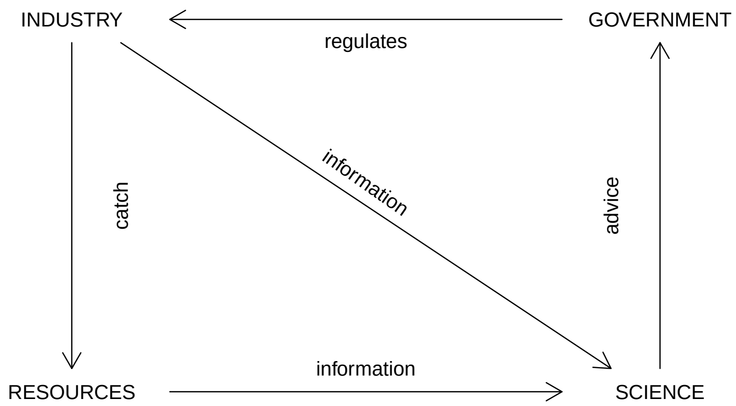

Figure 1: Management cycle

Figure 2 places the `MSE` components on top of the management cycle. The fleet and the stocks are embedded in an operating model, which is the representation of the natural and fishery systems. On the other side, the management procedure includes the stock assessment process, carried out by scientific institutions and experts, and the management process, carried out by the governmental institutions based on scientific advice. Two other important components are the observation error, which represents the process of collecting information for scientific purposes, and the implementation error, which accounts for differences between the intended results of the regulatory processes and the observed results, and incorporates the way the actors implement regulations and perceive the management objectives behind them.

The `a4a` approach to `MSE` is to develop a set of common methods and procedures to build a minimal standard `MSE` algorithm. This has the most common elements of both uncertainty and management options. Such a toolset should allow for the development of `MSE` simulations for many fisheries in an operational time frame.

The `a4a MSE` design uses a two step approach. The first step defines the 'standard' components of an `MSE` while the second step sets the details, for example the `HCR` or the `OM` conditioning.

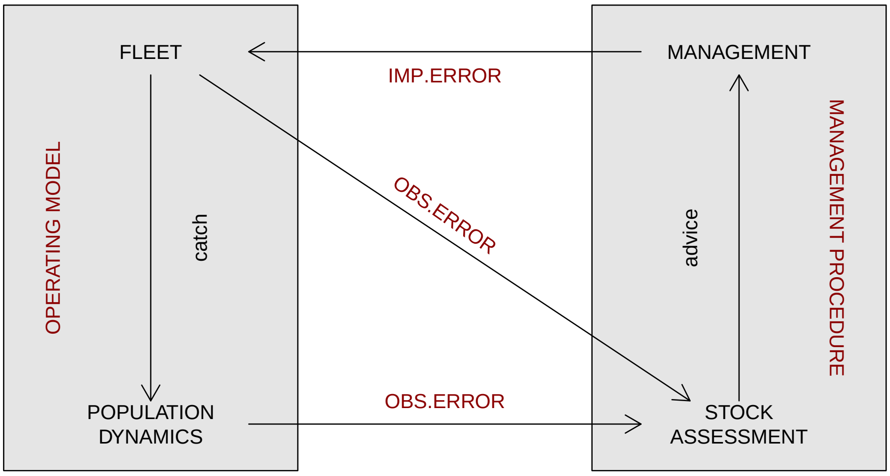

Figure 2: Management Strategies Evaluation

For background information on `a4a` check the `FLa4a` introductory vignette[1].

For more information on the `a4a` methodologies refer to Jardim, et.al, 2014, Millar, et.al, 2014 and Scott, et.al, 2016.

2 Notation and Definition of variables

Table 1 presents the variables used in this document. The following notation will be used for the defined variables, functions and indices.

Variables in the Operating Model (OM) are always uppercase, whiles variables in the Management Procedure (MP) are lowercase, *e.g.* catch C in OM c in the MP. Quantities estimated within the MP, *e.g.* fishing mortality by a stock assessment model, will use the uppercase with a hat, *e.g.* $\hat{F}$.

Functions will be represented with lower case letters. Functions estimated within the MP will be identified with a hat, *e.g.* the stock-recruitment function[2].

The target value that results from a decision process, *e.g.* the application of a harvest control rule, is identified by a tilde, $\tilde{F}$. Indices will always use lowercase, with their maximum value represented by the corresponding uppercase letter, *e.g.* ages as $a = 1 \ldots A$.

[1] `vignette("introduction", package="FLa4a")`

[2] The S/R estimation means not only the parameters but also the choice of the functional form, which depends of the perception of the stock on that moment.

Subject	Notation	Description
Variables		
	N	population abundance in number of individuals
	R	recruitment in number of individuals
	F	fishing mortality rate
	M	natural mortality rate
	B	mature biomass in weight
	W	individual mean weight
	P	percentage of mature fish
	C	catch in number of individuals
	Y	yield in weight
	Q	fleet catchability
	S	fleet selectivity
	E	fleet effort
	V	indicator of stock status
	D	abundance index
Functions		
	g	stock-recruitment function
	j	fleet behaviour
	f	stock assessment model or indicator
	x	management decision/harvest control rule parametrization
	h	management decision/harvest control rule
	k	management system
	w	technical measures
	l	implementation error
	o	observation error
Other		
	μ	expected value
	σ^2,Σ	variance or covariance matrix
	θ	set of parameters
	ϕ	median
	LN	lognormal probability density distribution
Indices		
	$a = 1 \dots A$	age
	$t = 1 \dots T$	years
	$i = 1 \dots N$	iterations
	trg	target

Table 1: Variables, indices and function, and the notation used to refer to them in the text.

2.1 Visualizing the `a4a` `MSE`

Recovering figure 2 and mapping the functions described above it becomes clearer how the algorithm is designed.

3 Operating model

Functions: $g(), j()$

The operating model includes the population dynamics of the stock

$$N_{a+1,t+1} = N_{a,t} \exp(-F_{a,t} - M_{a,t})$$

while for the first age, recruitment is estimated following some function of the adult biomass $g(B)$

$$N_{0,t} = R_t = g(B_t)$$

which is in turn dependent on the proportion of mature individuals at age (P_a) and the mean weight at age in the stock (W_a)

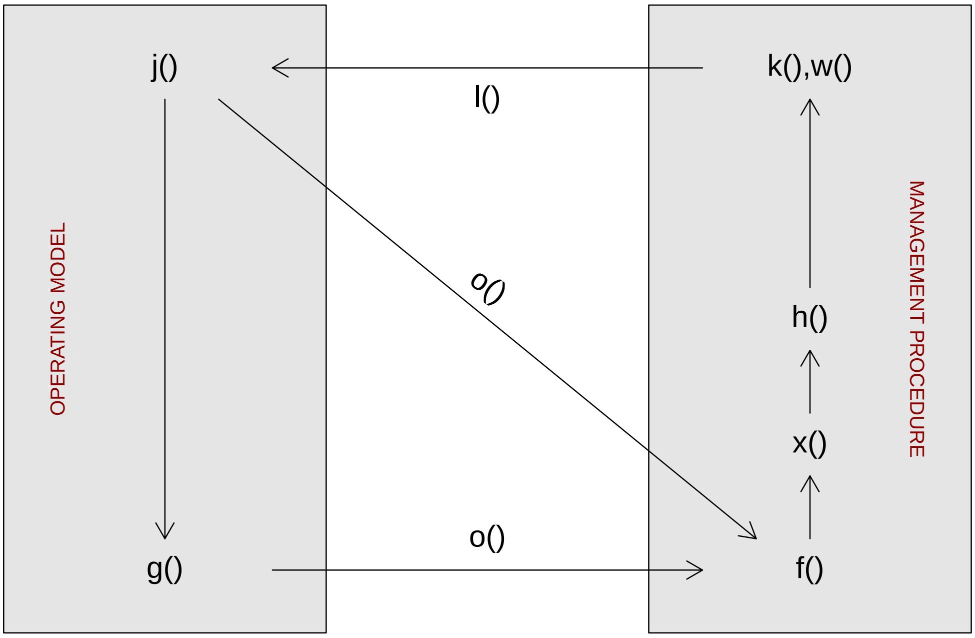

Figure 3: The `a4a` `MSE` algorithm

$$B_t = \sum_{a=1}^{A} W_{a,t} N_{a,t} P_{a,t}$$

Calculation of catch at age in numbers follows the standard Baranov equation

$$C_{a,t} = \frac{F_{a,t}}{F_{a,t} + M_{a,t}} N_{a,t} (1 - \exp(-F_{a,t} - M_{a,t}))$$

while total yield in weight is calculated as

$$Y_t = \sum_{a=1}^{A} W_{a,t} C_{a,t}$$

Fishing mortality at age is related to effort through selectivity-at-age, catchability and effort through the (possibly non-linear) function (j).

$$F_{a,t} = j(S_{a,t}, Q_t, E_t)$$

4 Observation error model

Function: $o()$

4.1 Catch in number of individuals, $c_{a,t}$

Catch in numbers-at-age[3] are observed with error

$$c_{a,t} = C_{a,t} \exp \epsilon_c$$

where ϵ_c is log-normally distributed

$$\epsilon_c \sim LN(\mu_c, \Sigma_c^2)$$

[3]Generally derived from sampling of numbers-at-length and a growth model or age-length key

4.2 Index of abundance, $d_{a,t}$

The index of abundance is observed with error, through catchability, which defines its relationship with the stock abundance-at-age

$$d_{a,t} = N_{a,t} q_{a,t} \exp \epsilon_d$$

where ϵ_d is log-normally distributed

$$\epsilon_d \sim LN(\mu_d, \Sigma_d^2)$$

5 Management procedure

5.1 Assessment/Estimator of stock statistics

Function: $f()$

Input into the decision rule includes the indicator of current status ($\hat{V}$), given the available information, in this case catches (c) and an index of abundance (d)

$$\hat{V} = f(c_{a,t}, d_{a,t} | \theta_f)$$

where

$$V \sim LN(\mu_v, \Sigma_v)$$

transformed through some suitable function (f), for example a stock assessment. The precise inputs, and the elements in θ will depend on the precise form of the HCR. In an age based system, for example, these would be estimates of F_t, B_t, C_t and/or $S_{a,t}$[4].

The stock assessment component of the status estimator might include an stock-recruitment relationship

$$\hat{N}_{0,t} = \hat{g}(\hat{B}_t)$$

$\hat{g}$ is the stock recruitment relationship estimated within the MP and represents the perceived dynamics, which may differ from the one included in the OM.

5.2 Parametrization of Management Decision/Harvest Control Rule (HCR)

Function: $x()$

This process sets the management references that will have to be used by the HCR to set exploitation levels in the future. When a stock assessment exists, this process is linked with the estimation of biological reference points (BRP). BRPs are afterwards translated, or transformed, into management reference points which set the objectives and limits of the HCR. The computation of these references may take place yearly or within a pre-specified period.

$$\theta_h = x(\hat{S}_{a,t}, \hat{g} | \theta_x)$$

where

$$\theta_h = \sim LN(\mu_h, \sigma_h)$$

5.3 Harvest Control Rule

Function: $h()$

In this code it is assumed that management is carried out through changes in F, although the implementation of those changes can be done through a combination of systems: input control, output control and/or technical measures. A first decision is made about the target fishing mortality for next year. The result of this decision is afterwards translated into an *implementation variable*.

$$\tilde{F}_{a+1,t+1} = h(\hat{F}_{a-1,t-1} | \theta_h)$$

where, for example $\theta_h = \{\hat{F}_{trg}, t_{trg}\}$.

[4] Which in our notation would be represented by $\hat{F}_t$, $\hat{B}_t$, $\hat{C}_t$ and/or $\hat{S}_{a,t}$

5.4 Management system

Function: $k()$

This process translates the management decision into a regulation, for example fishing opportunities, or days at sea. It mimics the process used to formulate the advice from the scientific estimates of likely effects of different fishing mortality levels.

5.4.1 Input/effort management

$$\tilde{E}_{t+1} = k(\tilde{F}_{a+1,t+1}|\theta_k) \exp \epsilon_{\tilde{E}}$$

$$\epsilon_{\tilde{E}} \sim LN(\mu_{\tilde{E}}, \sigma^2_{\tilde{E}})$$

5.4.2 Output/TAC management

$$\tilde{C}_{t+1} = k(\tilde{F}_{a+1,t+1}|\theta_k) \exp \epsilon_{\tilde{C}}$$

$$\epsilon_{\tilde{C}} \sim LN(\mu_{\tilde{C}}, \sigma^2_{\tilde{C}})$$

5.5 Technical measures

Function: $w()$

Technical measures affect the exploitation by imposing a shift in the age structure of the catch. Both gear selectivity or availability can be mimicked using shifts in the age structure of the exploitation. The overall level of exploitation is dealt by the input or output controls and technical measures are seen as a complement.

$$\tilde{S}_{a,t+1} = w(\hat{S}_{a,t}|\theta_w)$$

6 Implementation error model

Function: $l()$

$$F_{a,t+1} = l(\{\tilde{E}_{t+1}, \tilde{C}_{t+1}\}, \tilde{S}_{a,t+1}|\theta_l) \exp \epsilon_F$$

$$\epsilon_F \sim LN(\mu_F, \sigma^2_F)$$

ANNEX III

(following page)

Access to files with code and data

The files with code and data for this study are in the JRC git repository (https://fishreg.jrc.ec.europa.eu/gitlab/gamitjo/2017-AdriaticSmallPelagics).

For security reasons a user and password must be created for each of the STECF members wanting to access the files. Please email to Ernesto Jardim (ernesto.jardim@ec.europa.eu) so he can take care of your access and help you with any issue regarding git.

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STECF

The Scientific, Technical and Economic Committee for Fisheries (STECF) has been established by the European Commission. The STECF is being consulted at regular intervals on matters pertaining to the conservation and management of living aquatic resources, including biological, economic, environmental, social and technical considerations.

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